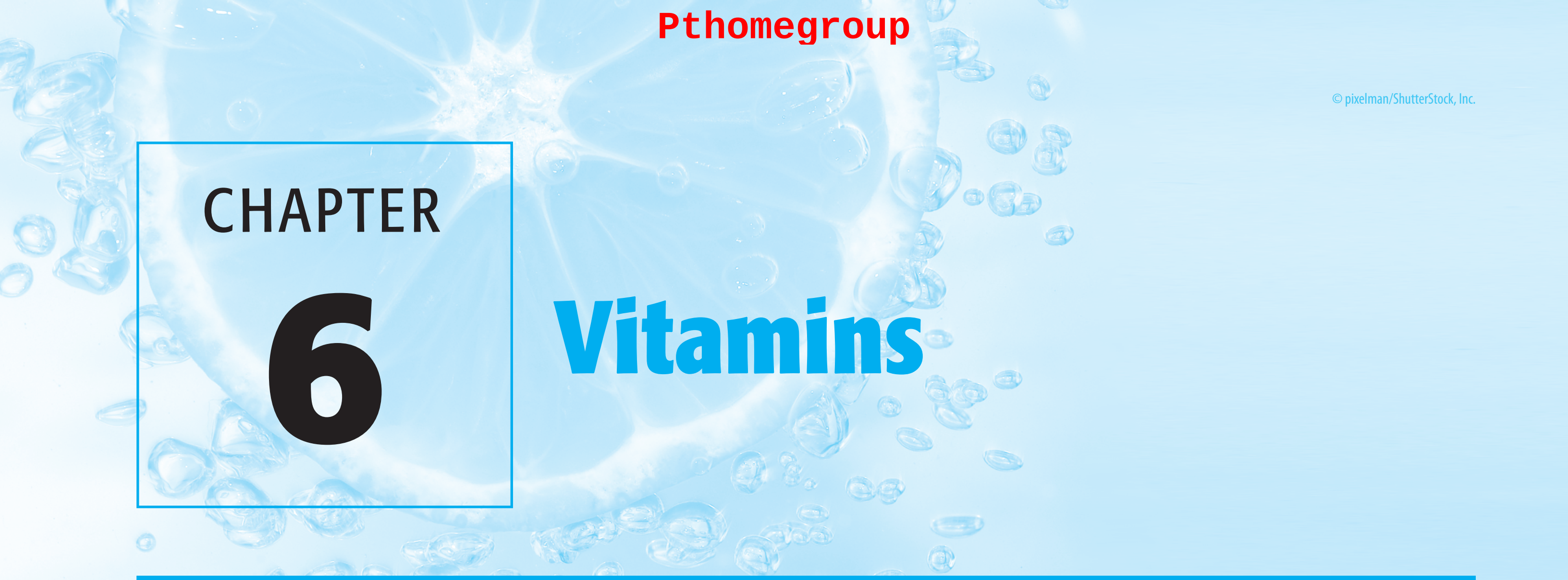


CHAPTER 6 Vitamins

Key Questions Addressed

- What's the big deal about vitamins?
- What are vitamins?
- How are the dietary needs for vitamins represented?
- What are the water-soluble vitamins?
- What are the fat-soluble vitamins?
- Which vitamins or compounds have antioxidant properties?
- What are phytochemicals?

You Are the Nutrition Coach

Roger is a starting guard on his college basketball team. He is a leader on his team, stays after practice to work on his shots, and is busy with academic and community life on campus. Because of his hectic schedule, he has little time for meal planning, grocery shopping, and food preparation. Dinner is usually consumed at the athletics training table during the week, and the rest of his meals are consumed either at home or at local restaurants. A 3-day food record kept by Roger recently was analyzed using a nutrition software program. The analysis revealed overall energy intake was not meeting his estimated needs, and vitamins A, C, and folate were consistently low throughout the 3-day period. The rest of the vitamins and minerals met the minimum RDA or AI requirements.

Questions

- What questions should you ask Roger about his typical daily diet?
- What recommendations do you have for Roger to improve his dietary intake of vitamins and his energy intake?
- How can you help Roger meet these recommendations?

What's the big deal about vitamins?

Vitamins play important roles throughout the body and are considered essential; without vitamins, the body could not function. Some vitamins can be synthesized in the body. Many are precursors for different processes, whereas others are critical for the development of various compounds in the body. For example, vitamin D serves as a precursor molecule in cholesterol formation, and beta-carotene serves as a precursor for vitamin A.

The role that vitamins play in sport performance has been studied over the years. Although it is clear that vitamins are crucial for body functions, less is known about the potential role they play in improving or hindering sport performance. Many athletes perceive that adequate vitamin intake is crucial to peak performance. Although the performance effect may not be proven, certain athlete populations are more prone to nutrient deficiencies, thus justifying a greater emphasis on a specific vitamin or mineral.[1] For example, female athletes may be more susceptible to iron deficiencies. Therefore, iron, as well as vitamins that enhance iron absorption, such as vitamin C, should receive greater emphasis in the diet. Another example that has recently received more attention is the potential for an increased need for some antioxidant vitamins and phytochemicals for those engaging in high-intensity training of long duration, which may increase oxidative stress within the body.

This chapter discusses the recommended levels of intake for vitamins, antioxidants, and phytochemicals for healthy individuals and for athletes. The functions of these nutrients, their effects on energy systems, deficiency and toxicity symptoms, their importance to sport performance, food sources, and meal-planning tips for athletes are discussed.

What are vitamins?

There are two classifications of vitamins: water soluble and fat soluble. The **water-soluble vitamins** include the B vitamins, vitamin C, and choline. These vitamins dissolve in water and are easily transported in the blood. Because of their water solubility they are also turned over in the body and as a result are not stored in the body in appreciable amounts. Utilization of water-soluble vitamins occurs on an as-needed basis; excess B vitamins or vitamin C are excreted in the urine. Because little storage of water-soluble vitamins occurs, regular intake of these nutrients is important.

water-soluble vitamins A class of vitamins that dissolve in water and are easily transported in the blood. The water-soluble vitamins are the B vitamins, vitamin C, and choline.

fat-soluble vitamins A group of vitamins that do not dissolve easily in water and require dietary fat for intestinal absorption and transport in the bloodstream. The fat-soluble vitamins are A, D, E, and K.

Fat-soluble vitamins do not dissolve easily in water and require dietary fat for intestinal absorption and transport in the bloodstream. Unlike water-soluble vitamins, the fat-soluble vitamins A, D, E, and K are stored in the body, primarily in fat tissue and the liver, as well as in other organs, though in smaller amounts. When taken in excess, stored levels of the fat-soluble vitamins can build up and become toxic to the body. Dietary intake from foods rarely causes a toxic buildup, but intake via high-dosage supplements can quickly and easily build these vitamins to toxic levels.

gaining the performance edge

Water- and fat-soluble vitamins are vital to human health. An emphasis should be placed on food sources of vitamins, rather than on supplements. These high-vitamin foods should be consumed on a daily basis.

How are the dietary needs for vitamins represented?

The Dietary Reference Intakes (DRIs) include several ways to quantify nutrient needs or excesses of vitamins and minerals. As a summary, the DRIs include the Recommended Dietary Allowance (RDA), Estimated Average Requirement (EAR), Adequate Intake (AI), and Tolerable Upper Intake Level (UL). Each vitamin may have one or more of the DRIs established, depending on availability of current research data (see **Table 6.1**). The majority of vitamins have an established RDA or AI, and some have a UL.

What are the water-soluble vitamins?

The water-soluble vitamins include the B-complex vitamins (thiamin, riboflavin, niacin, B_6, B_{12}, folate, biotin, and pantothenic acid), choline, and vitamin C. Water-soluble vitamins are involved in many different processes within the body, including acting as **coenzymes**. A coenzyme is an organic molecule, usually a B vitamin, that attaches to an enzyme and activates or increases its ability to catalyze

coenzymes An organic molecule, usually a B vitamin, that attaches to an enzyme and activates or increases its ability to catalyze metabolic reactions.

TABLE 6.1 Dietary Reference Intakes (DRIs) for Vitamins

Life Stage Group	Vitamin A (μg/d)[1]	Vitamin D (IU/d)[2]	Vitamin E (mg/d)[3]	Vitamin K (μg/d)	Thiamin (mg/d)	Riboflavin (mg/d)	Niacin (mg/d)[4]	Panothenic Acid (mg/d)	Biotin (μg/d)	Vitamin B_6 (mg/d)	Folate (μg/d)[5]	Vitamin B_{12} (μg/d)	Vitamin C (mg/d)	Choline (mg/day)
Infants														
0–6 months	400*	400*	4*	2.0*	0.2*	0.3*	2*	1.7*	5*	0.1*	65*	0.4*	40*	125*
7–12 months	500*	400*	5*	2.5*	0.3*	0.4*	4*	1.8*	6*	0.3*	80*	0.5*	50*	150*
Children														
1–3 years	300	600	6	30*	0.5	0.5	6	2*	8*	0.5	150	0.9	15	200*
4–8 years	400	600	7	55*	0.6	0.6	8	3*	12*	0.6	200	1.2	25	250*
Males														
9–13 years	600	600	11	60*	0.9	0.9	12	4*	20*	1.0	300	1.8	45	375*
14–18 years	900	600	15	75*	1.2	1.3	16	5*	25*	1.3	400	2.4	75	550*
19–30 years	900	600	15	120*	1.2	1.3	16	5*	30*	1.3	400	2.4	90	550*
31–50 years	900	600	15	120*	1.2	1.3	16	5*	30*	1.3	400	2.4	90	550*
51–70 years	900	600	15	120*	1.2	1.3	16	5*	30*	1.7	400	2.4[7]	90	550*
>70 years	900	800	15	120*	1.2	1.3	16	5*	30*	1.7	400	2.4[7]	90	550*
Females														
9–13 years	600	600	11	60*	0.9	0.9	12	4*	20*	1.0	300	1.8	45	375*
14–18 years	700	600	15	75*	1.0	1.0	14	5*	25*	1.2	400[6]	2.4	65	400*
19–30 years	700	600	15	90*	1.1	1.1	14	5*	30*	1.3	400[6]	2.4	75	425*
31–50 years	700	600	15	90*	1.1	1.1	14	5*	30*	1.3	400[6]	2.4	75	425*
51–70 years	700	600	15	90*	1.1	1.1	14	5*	30*	1.5	400	2.4[7]	75	425*
>70 years	700	800	15	90*	1.1	1.1	14	5*	30*	1.5	400	2.4[7]	75	425*
Pregnancy														
≤18 years	750	600	15	75*	1.4	1.4	18	6*	30*	1.9	600	2.6	80	450*
19–30 years	770	600	15	90*	1.4	1.4	18	6*	30*	1.9	600	2.6	85	450*
31–50 years	770	600	15	90*	1.4	1.4	18	6*	30*	1.9	600	2.6	85	450*
Lactation														
≤18 years	1200	600	19	75*	1.4	1.6	17	7*	35*	2.0	500	2.8	115	550*
19–30 years	1300	600	19	90*	1.4	1.6	17	7*	35*	2.0	500	2.8	120	550*
31–50 years	1300	600	19	90*	1.4	1.6	17	7*	35*	2.0	500	2.8	120	550*

This table presents Recommended Dietary Allowances (RDA) and Adequate Intakes (AI). An asterisk (*) indicates AI. RDAs and AIs may both be used as goals for individual intake.

[1]As retinol activity equivalents (RAE).

[2]As cholecalciferol.

[3]As α-tocopherol.

[4]As niacin equivalents (NE).

[5]As dietary folate equivalents (DFE).

[6]In view of evidence linking folate intake with lessening of neural-tube defects in the fetus, it is recommended that all women capable of becoming pregnant consume 400 μg of folic acid from supplements or fortified foods in addition to intake of food folate from a varied diet.

[7]Because 10–30% of older people may malabsorb food-bound vitamin B_{12}, it is advisable for those older than 50 years to meet their RDA mainly by consuming foods fortified with vitamin B_{12} or a supplement containing vitamin B_{12}.

Sources: Data from Institute of Medicine's *Dietary Reference Intakes for Thiamin, Riboflavin, Niacin, Vitamin B_6, Folate, Vitamin B_{12}, Pantothenic Acid, Biotin, and Choline.* Food and Nutrition Board. Washington, DC: National Academies Press, 1998; *Dietary Reference Intakes for Vitamin A, Vitamin K, Arsenic, Boron, Chromium, Copper, Iodine, Iron, Manganese, Molybdenum, Nickel, Silicon, Vanadium and Zinc.* Food and Nutrition Board. Washington, DC: National Academies Press, 2001; *Dietary Reference Intakes for Vitamin C, Vitamin E, Selenium, and Carotenoids.* Food and Nutrition Board. Washington, DC: National Academies Press, 2000; Institute of Medicine; *Dietary Reference Intakes for Calcium and Vitamin D.* Food and Nutrition Board. Washington, DC: National Academies Press, 2011.

metabolic reactions. Some of these metabolic reactions are critical for energy production, especially during exercise.

Water-soluble vitamins can be obtained naturally from a large variety of food sources as well as from vitamin-fortified foods and beverages. In general, water-soluble vitamins are destroyed or lost with excessive cooking. To maximize the benefit of eating foods rich in the B-complex and C vitamins, foods should be eaten raw or cooked for short periods of time. The exception to this rule is any meat product. Meats should be cooked thoroughly to prevent foodborne pathogens found in undercooked meats. Because water-soluble vitamins are not stored to any great extent in the body, it is important to eat foods containing these vitamins on a daily basis.

Why is thiamin important to athletes?

Thiamin is also referred to as vitamin B_1. It is absorbed in the small intestine and is stored mainly in skeletal muscle, the liver, the kidneys, and the brain. Thiamin plays a major role in energy production and is also important for developing and maintaining a healthy nervous system. In relation to performance, thiamin is a component of the coenzyme thiamin pyrophosphate that converts pyruvate into acetyl CoA, which then enters into the Krebs cycle during aerobic energy production. Thiamin also plays a role in the conversion and utilization of glycogen for energy as well as the catabolism of branched chain amino acids. Some studies have shown that athletes with low intakes of thiamin have diminished exercise endurance.

What is the RDA/AI for thiamin?

The RDA for thiamin is 1.2 milligrams for males and 1.1 milligrams for females.[2] The RDA is based on the notion that humans need approximately 0.5 milligrams of thiamin per 1000 calories ingested daily. Therefore, thiamin requirements escalate with increased calorie intake. Athletes, who are generally expending more calories through training and competition relative to the sedentary population, will require more thiamin than the RDA on a daily basis. Thiamin is also critical for the proper metabolism of carbohydrates, so as carbohydrate intake increases, so will the requirement for thiamin.

What are the complications of thiamin deficiency?

Thiamin deficiency is typically caused by an athlete consuming very few calories or having a diet composed mainly of processed foods. The signs and symptoms of thiamin deficiency include decreased appetite, mental confusion, headaches, fatigue, muscle weakness, nerve degeneration, and pain in the calf muscles. If a severe deficiency is left untreated for as little as 10 days, the disease beriberi can develop, which can lead to damage to the heart and nervous system. In regard to performance, studies have found that athletes with low intakes of thiamin and other water-soluble vitamins over the course of 11 weeks suffer decreases in maximal work capacity, peak power, and mean power output.[3,4]

What are the symptoms of thiamin toxicity?

As discussed earlier, water-soluble vitamins tend not to accumulate in the body because any excess is excreted in the urine. As a result, the risk for thiamin toxicity is low, and therefore no upper limit has been set for thiamin intake.

Which foods are rich in thiamin?

Thiamin is found in a variety of foods, including whole grains, legumes, wheat germ, nuts, pork, and fortified foods, such as refined flours, grains, and breakfast cereals (see Figure 6.1). In the United States, thiamin needs are generally met with a well-balanced diet and adequate total daily calories.

What is a suggestion for a thiamin-rich meal or snack?

Breakfast: One packet of instant oatmeal, made with 8 oz soy milk and topped with ¼ cup sunflower or pumpkin seeds
Total thiamin content = 0.768 milligrams

Do athletes need thiamin supplements?

Research on the ergogenic effects of thiamin supplementation is limited and has provided inconclusive results. Most studies have found that athletes who are restricting intake for the purposes of weight loss could potentially be low in thiamin[3,5] and therefore would benefit from a supplement. However, as with all nutrients, the focus should first be on nutrient-rich foods, and then a supplement if indicated.

Why is riboflavin important for athletes?

Riboflavin is also commonly referred to as vitamin B_2. It is absorbed mainly in the small intestine. Riboflavin is highly involved in the aerobic production of energy (i.e., ATP) from carbohydrates, proteins, and fats. The two coenzymes, flavin mononucleotide and flavin adenine dinucleotide, contain riboflavin and are involved in the transport of electrons to the electron transport chain

THIAMIN

Daily Value = 1.5 mg
RDA = 1.2 mg (males), 1.1 mg (females)

	Food	Amount	Thiamin
	Exceptionally good source		
	Sweet potato, cooked	140 g (1 potato)	2.0 mg
High: 20% DV or more	Pork, loin roast, lean only, cooked	85 g (3 oz)	0.76 mg
	Ham, extra lean, cooked	85 g (3 oz)	0.63 mg
	Bagel, plain	90 g (1 4" bagel)	0.48 mg
	Fish, tuna, cooked	85 g (3 oz)	0.43 mg
	Soy milk	240 mL	0.39 mg
	Corn flakes cereal	30 g (1 cup)	0.39 mg
	Cheerios cereal	30 g (1 cup)	0.38 mg
	Fiber One cereal	30 g (1/2 cup)	0.38 mg
	Oatmeal, instant, fortified, cooked	1 cup	0.34 mg
Good: 10–19% DV	Spaghetti, enriched, cooked	140 g (1 cup)	0.29 mg
	Wheat germ	15 g (1/4 cup)	0.28 mg
	Orange juice, chilled	240 mL (1 cup)	0.28 mg
	Sesame seeds	30 g (~1 oz)	0.24 mg
	Rice, white, enriched, cooked	140 g (~3/4 cup)	0.23 mg
	Salmon, cooked	85 g (3 oz)	0.23 mg
	White bread, enriched	50 g (2 slices)	0.23 mg
	Soybeans, cooked	90 g (~1/2 cup)	0.23 mg
	Black beans, cooked	90 g (~1/2 cup)	0.22 mg
	Pecans	30 g (~1 oz)	0.20 mg
	Grits, corn, enriched, cooked	1 cup	0.20 mg
	Whole wheat bread	50 g (2 slices)	0.20 mg
	Brazil nuts	30 g (~1 oz)	0.19 mg
	Baked beans, canned	130 g (~1/2 cup)	0.19 mg
	Navy beans, cooked	90 g (~1/2 cup)	0.18 mg
	Oysters, cooked	85 g (3 oz)	0.16 mg
	Lentils, cooked	90 g (~1/2 cup)	0.15 mg

Figure 6.1 Food sources of thiamin. Pork, whole and enriched grains, and fortified cereals are rich in thiamin. Most animal foods, however, contain little thiamin. Note: The DV for thiamin is higher than the current RDA of 1.2 and 1.1 milligrams for males and females, respectively, age 19 and older.

Source: Data from U.S. Department of Agriculture, Agricultural Research Service, 2012. USDA National Nutrient Database for Standard Reference, Release 25. Nutrient Data Laboratory home page. Available at: http://www.ars.usda.gov/ba/bhnrc/ndl.

during aerobic energy production at rest and during exercise.

What is the RDA/AI for riboflavin?

The RDA for riboflavin is 1.3 milligrams for males and 1.1 milligrams for females.[2]

What are the complications of riboflavin deficiency?

Riboflavin deficiency is recognized by symptoms such as red lips, cracks at the corners of the mouth, a sore throat, or an inflamed tongue. In athletics, a riboflavin deficiency may contribute to poor performance. One investigation found that 19% of the young active boys studied had poor riboflavin status. After 2 months of riboflavin supplementation, performance in a maximal bicycle ergometer test improved as compared to presupplementation.[6]

What are the symptoms of riboflavin toxicity?

As with most water-soluble vitamins, there appear to be no adverse effects of high doses of riboflavin because dietary excess is excreted in urine. Therefore, no upper limit has been set for riboflavin.

Which foods are rich in riboflavin?

Figure 6.2 lists some of the foods containing riboflavin. Milk, yogurt, bread, cereal products, mushrooms, cottage cheese, and eggs are all good sources of riboflavin. Similar to thiamin, bread and cereal products in the United States are fortified with riboflavin.

What is a suggestion for a riboflavin-rich meal or snack?

Salad bar creation: 2 cups of romaine lettuce with ½ cup each of mushrooms, carrots, and cottage cheese, and 2 tbsp of almonds
Total riboflavin content = 0.661 milligrams

Do athletes need riboflavin supplements?

It is challenging to determine whether athletes need riboflavin supplements. Minimal research has been conducted on the riboflavin status of individuals exercising strenuously[5] or the performance effects of riboflavin supplementation. A study conducted by Winters et al.[7] focused on women 50 to 67 years of age who exercised for 20 to 25 minutes, 6 days a week for 4-week periods on a cycle ergometer at 75–85% of their maximal heart rate. Although the investigators found biochemical changes indicating riboflavin depletion, supplemental riboflavin did not enhance exercise performance or endurance. More research is warranted to make a recommendation on whether athletes require more riboflavin than the current RDA. Daily riboflavin needs can typically be met through a balanced and calorically adequate diet.

Why is niacin important for athletes?

Niacin is a general term for two different substances: nicotinic acid and nicotinamide. Some sources might refer to niacin as vitamin B_3. A majority of niacin absorption occurs in the intestines, but a small amount is absorbed through the stomach. Niacin is highly involved in energy production and mitochondrial metabolism, thus affecting muscular and nervous

RIBOFLAVIN

Daily Value = 1.7 mg
RDA = 1.3 mg (males), 1.1 mg (females)

	Food	Serving	Riboflavin
	Exceptionally good sources		
	Beef liver, cooked	85 g (3 oz)	2.9 mg
	Chicken liver, cooked	85 g (3 oz)	1.96 mg
	Wheat bran flakes cereal	30 g (3/4 cup)	1.77 mg
High: 20% DV or more	Yogurt, plain, nonfat	225 g (1 8-oz container)	0.53 mg
	Yogurt, plain, low-fat	225 g (1 8-oz container)	0.48 mg
	Milk, nonfat	240 mL (1 cup)	0.47 mg
	Corn flakes cereal	30 g (1 cup)	0.46 mg
	Milk, 1%, 2%, whole (3.25%)	240 mL (1 cup)	0.45 mg
	Cheerios cereal	30 g (1 cup)	0.43 mg
	Fiber One cereal	30 g (1/2 cup)	0.43 mg
	Oatmeal, instant, fortified, cooked	1 cup	0.40 mg
	Squid, cooked	85 g (3 oz)	0.39 mg
	Buttermilk, low-fat	240 mL (1 cup)	0.38 mg
	Clams, cooked	85 g (3 oz)	0.36 mg
Good: 10–19% DV	Egg, hardcooked	50 g (1 large)	0.26 mg
	Soybeans, cooked	90 g (~1/2 cup)	0.26 mg
	Mushrooms, cooked	85 g (~1/2 cup)	0.26 mg
	Herring, cooked	85 g (3 oz)	0.25 mg
	Almonds	30 g (~1 oz)	0.24 mg
	Pork, loin chops, lean only, cooked	85 g (3 oz)	0.23 mg
	Turkey, dark meat, cooked	85 g (3 oz)	0.21 mg
	Spinach, cooked	85 g (~1/2 cup)	0.20 mg
	Cottage cheese, 2% milkfat	110 g (~1/2 cup)	0.20 mg
	Chicken, dark meat, cooked	85 g (3 oz)	0.19 mg
	Beef, porterhouse steak, cooked	85 g (3 oz)	0.18 mg
	Ham, extra lean, cooked	85 g (3 oz)	0.17 mg
	Soy milk	240 mL (1 cup)	0.17 mg
	White bread, enriched	50 g (2 slices)	0.17 mg

Figure 6.2 Food sources of riboflavin. The best sources of riboflavin include milk, liver, whole and enriched grains, and fortified cereals. Note: The DV for riboflavin is higher than the current RDA of 1.3 and 1.1 milligrams for males and females, respectively, age 19 and older.

Source: Data from U.S. Department of Agriculture, Agricultural Research Service, 2012. USDA National Nutrient Database for Standard Reference, Release 25. Nutrient Data Laboratory home page. Available at: http://www.ars.usda.gov/ba/bhnrc/ndl.

system function. Niacin is a component of two coenzymes: nicotinamide adenine dinucleotide (NAD+) and nicotinamide adenine dinucleotide phosphate (NADP+). These coenzymes are involved in the transfer of hydrogen ions in the anaerobic and aerobic energy systems. During aerobic exercise, NAD+ can accept a hydrogen ion and become NADH, carrying high-energy electrons to the electron transport chain for the production of ATP. In anaerobic metabolism, NADH is responsible for transferring hydrogen to pyruvate to form lactate during the breakdown of carbohydrates for energy.

What is the RDA/AI for niacin?

The RDA for niacin is 16 milligrams for males and 14 milligrams for females.[2] Niacin is obtained through the diet but can also be formed within the body from the amino acid tryptophan. Therefore, the RDA refers to niacin equivalents (NE), reflecting intake from niacin-rich foods as well as sources of tryptophan that can be converted into niacin. For foods rich in tryptophan, 60 milligrams of tryptophan is equivalent to 1 milligram of niacin.

What are the complications of niacin deficiency?

Niacin is critical for the progression of many metabolic pathways, and therefore a niacin deficiency will affect many bodily systems. Signs and symptoms of niacin deficiency include loss of appetite, skin rashes, mental confusion, lack of energy, and muscle weakness. If the deficiency is left untreated, the deficiency disease pellagra develops. Pellagra is characterized by the three “Ds”: dementia (mental confusion), diarrhea, and dermatitis (skin rashes). If pellagra is left untreated, there is a fourth “D,” death.

What are the symptoms of niacin toxicity?

The upper dietary limit is 35 milligrams per day. Common side effects of high niacin intake include flushing of the face, arms, and chest; itchy skin rashes; headaches; nausea; glucose intolerance; blurred vision; and ultimately, liver complications. Doses several times the RDA are used medicinally for lowering LDL and raising HDL cholesterol. Individuals taking niacin for its cholesterol-lowering effect must be under the supervision of a physician to monitor any potential complications and decrease the risk for liver damage.

Which foods are rich in niacin?

Along with thiamin and riboflavin, refined flours, grains, and cereals are fortified with niacin. Other dietary sources include protein-rich foods such as beef, poultry, fish, legumes, liver, and seafood, as well as whole grain products and mushrooms (see Figure 6.3).

What is a suggestion for a niacin-rich meal or snack?

Dining out—Italian: Chicken marsala (4 oz chicken in 1 cup mushroom sauce) on 2 cups spaghetti
Total niacin content = 24 milligrams

NIACIN

Daily Value = 20 mg
RDA = 16 mg (males), 14 mg (females)

High: 20% DV or more	Beef liver, cooked	85 g (3 oz)	14.9 mg
	Chicken, light meat, cooked	85 g (3 oz)	10.6 mg
	Chicken liver, cooked	85 g (3 oz)	9.4 mg
	Salmon, cooked	85 g (3 oz)	8.6 mg
	Tuna, canned	55 g (2 oz)	7.3 mg
	Halibut, cooked	85 g (3 oz)	6.1 mg
	Turkey, light meat, cooked	85 g (3 oz)	5.8 mg
	Chicken, dark meat, cooked	85 g (3 oz)	5.6 mg
	Beef, ground, extra lean, cooked	85 g (3 oz)	5.3 mg
	Corn flakes, Cheerios cereals	30 g (1 cup)	5.0 mg
	Fiber One cereal	30 g (1/2 cup)	5.0 mg
	Oatmeal, instant, fortified, cooked	1 cup	4.8 mg
	All Bran cereal	30 g (1/2 cup)	4.8 mg
	Peanut butter	2 Tbsp	4.3 mg
	Pork, loin roast, lean only, cooked	85 g (3 oz)	4.0 mg
	Tomato paste, canned	130 g (~1/2 cup)	4.0 mg
Good: 10–19% DV	Beef, T-bone steak, cooked	85 g (3 oz)	3.9 mg
	Mushrooms, cooked	85 g (~1/2 cup)	3.8 mg
	Salmon, canned, solids + bones	55 g (2 oz)	3.6 mg
	Ham, extra lean, cooked	85 g (3 oz)	3.4 mg
	Beef, porterhouse steak, cooked	85 g (3 oz)	3.2 mg
	Turkey, dark meat, cooked	85 g (3 oz)	3.1 mg
	Barley, cooked	140 g (~1 cup)	2.9 mg
	Sardines, canned, solids + bones	55 g (2 oz)	2.9 mg
	Clams, cooked	85 g (3 oz)	2.9 mg
	Spaghetti, enriched, cooked	140 g (1 cup)	2.3 mg
	Shrimp, cooked	85 g (3 oz)	2.2 mg
	White bread, enriched	50 g (2 slices)	2.2 mg
	Rice, brown, cooked	140 g (~3/4 cup)	2.1 mg
	Cod, cooked	85 g (3 oz)	2.1 mg
	Rice, white, enriched, cooked	140 g (~3/4 cup)	2.0 mg

Figure 6.3 Food sources of niacin. Niacin is found mainly in meats and grains. Enrichment adds niacin as well as thiamin, riboflavin, folic acid, and iron to processed grains. Note: The DV for niacin is higher than the current RDA of 16 and 14 milligrams for males and females, respectively, age 19 and older.

Source: Data from U.S. Department of Agriculture, Agricultural Research Service, 2012. USDA National Nutrient Database for Standard Reference, Release 25. Nutrient Data Laboratory home page. Available at: http://www.ars.usda.gov/ba/bhnrc/ndl.

Do athletes need niacin supplements?

Although niacin is crucial for facilitating energy production, recent research reviews have concluded that well-nourished athletes do not benefit from niacin supplements. In addition to the lack of apparent benefit of consuming extra niacin, supplements are not recommended because high doses of niacin can:

- Affect fat metabolism by blocking free fatty acid release from adipose tissue,[8–10] increasing the reliance of the body on carbohydrate stores, thus depleting glycogen stores.[11]
- Increase blood flow to the skin, which decreases heat storage. This may be beneficial/ergogenic for some athletes, but more research is needed.[12]

Why is vitamin B_6 important for athletes?

Vitamin B_6 refers to all biologically active forms of vitamin B_6, including pyridoxine, pyridoxal, pyridoxamine, pyridoxine phosphate, pyridoxal phosphate, and pyridoxamine phosphate. Pyridoxine, pyridoxal, and pyridoxamine are the forms most commonly found in foods. All forms of vitamin B_6 are absorbed mainly in the jejunum of the small intestine and are converted in the liver to the most active coenzyme form, pyridoxal phosphate. Vitamin B_6 is important for health and athletic performance in many ways. B_6 is a component of more than 100 enzymes, which facilitate the following:

- *The breakdown of glycogen for energy as well as gluconeogenesis in the liver:* Both processes are important during endurance activities.
- *The synthesis of amino acids via transamination:* This process produces amino acids endogenously, meaning that not all amino acids need to be consumed through the diet.
- *The conversion of tryptophan to niacin:* Daily niacin requirements are based on a combination of niacin consumed through foods and the amount made by the body from tryptophan.
- *The formation of neurotransmitters:* This is critical for the fine motor movement and control required for various sports.
- *The production of the red blood cells' hemoglobin ring:* Hemoglobin is essential for endurance activities that rely on oxygen for energy. A deficiency in B_6 can contribute to microcytic hypochromic anemia (small, low-hemoglobin red blood cells).
- *The production of white blood cells:* This is critical for proper immune function.

Vitamin B_6 has recently been heralded as a dietary protector against heart disease. Research has found that individuals with low intakes of B_6, as well as folate and vitamin B_{12}, have higher blood levels of homocysteine, which is a risk factor for heart disease (see Figure 6.4).

What is the RDA/AI for vitamin B_6?

The RDA for men and women ages 19 to 50 is 1.3 milligrams.[2] Because of the role of vitamin B_6 in protein metabolism, requirements are based on

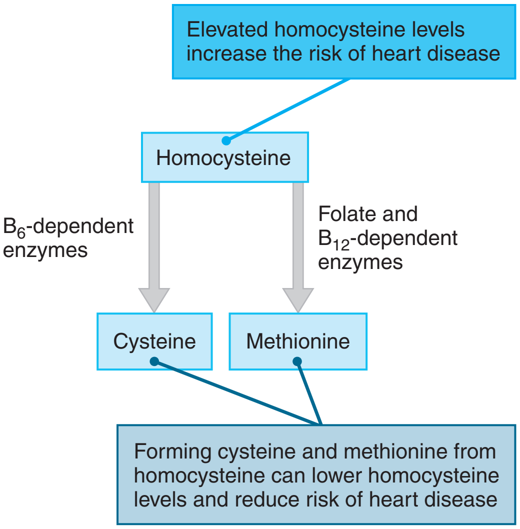


Figure 6.4 Homocysteine and heart disease. Elevated homocysteine levels are linked to an increased risk of heart disease. B_6, B_{12}, and folate-dependent enzymes help lower the amount of homocysteine by converting it to cysteine and methionine.

protein intake. Individuals following a high-protein diet may need to consume more vitamin B_6.

What are the complications of vitamin B_6 deficiency?

Deficiencies in vitamin B_6 in male and female athletes are rare.[13] When athletes fail to ingest adequate vitamin B_6, it is usually explained by low energy intakes and poor food choices.[13] It is interesting to note that even when consuming a diet low in vitamin B_6, one study demonstrated that muscle levels of vitamin B_6 were not depleted.[14] However, if low daily intake persists, or if an athlete is taking diuretics or oral contraceptives, B_6 deficiency is still a possibility. For example, Manore et al.[15] studied three different groups of women, active and sedentary, and found that the elderly groups had low intakes of vitamin B_6 in their daily diets. A vitamin B_6 deficiency can be detected by symptoms such as nausea, impaired immune function (because of low numbers of white blood cells), convulsions, depression (related to the improper functioning of neurotransmitters), skin disorders, mouth sores, weakness, and anemia (because of low levels of red blood cell production).

What are the symptoms of vitamin B_6 toxicity?

The upper limit for vitamin B_6 is 100 milligrams per day. Impaired gait resulting from peripheral nerve damage can be caused by intakes at or slightly above the upper daily limit. Irreversible nerve damage can occur at levels of 1000–2000 milligrams per day.

Which foods are rich in vitamin B_6?

Vitamin B_6 is found in a variety of foods (see Figure 6.5). The richest sources include high-protein foods such as beef, poultry, fish, and eggs. Other significant sources include whole grains, brown rice, wheat germ, white potatoes, starchy vegetables, fortified soy-based meat analogs, and bananas. It should be noted that refined grain products have been stripped of most of their B_6 content. Unlike with thiamin, riboflavin, and niacin, the enrichment process does not replace the lost B_6 in foods.

VITAMIN B_6

Daily Value = 2 mg
RDA = 1.3 mg (males/females)

	Food	Serving	Amount
	Exceptionally good source		
	Wheat bran flakes cereal	30 g (3/4 cup)	2.1 mg
High: 20% DV or more	All Bran cereal	30 g (1/2 cup)	1.8 mg
	Beef liver, cooked	85 g (3 oz)	0.9 mg
	Chicken, light meat, cooked	85 g (3 oz)	0.7 mg
	Chicken liver, cooked	85 g (3 oz)	0.6 mg
	Garbanzo beans, canned	130 g (~1/2 cup)	0.6 mg
	Banana, fresh	140 g (1 9" banana)	0.5 mg
	Corn flakes cereal	30 g (1 cup)	0.5 mg
	Fiber One cereal	30 g (1/2 cup)	0.5 mg
	Cheerios cereal	30 g (1 cup)	0.5 mg
	Turkey, light meat, cooked	85 g (3 oz)	0.5 mg
	Pork, loin roast, lean only	85 g (3 oz)	0.4 mg
	Beef, ground, extra lean, cooked	85 g (3 oz)	0.4 mg
Good: 10–19% DV	Ham, extra lean, cooked	85 g (3 oz)	0.3 mg
	Halibut, cooked	85 g (3 oz)	0.3 mg
	Potato, baked, w/skin	110 g (1 small)	0.3 mg
	Turkey, dark meat, cooked	85 g (3 oz)	0.3 mg
	Chicken, dark meat, cooked	85 g (3 oz)	0.3 mg
	Beef, porterhouse steak, cooked	85 g (3 oz)	0.3 mg
	Herring, cooked	85 g (3 oz)	0.3 mg
	Tomato juice, canned	240 mL (1 cup)	0.3 mg
	Sweet potato, cooked	110 g (1 small)	0.3 mg
	Sesame seeds	30 g (~1 oz)	0.2 mg
	Sunflower seeds	30 g (~1 oz)	0.2 mg

Figure 6.5 Food sources of vitamin B_6. Meats are generally good sources of vitamin B_6, as are certain fruits (e.g., bananas) and vegetables (e.g., potatoes, carrots). Note: The DV for vitamin B_6 is higher than the current RDA of 1.3 milligrams for males and females age 19 and older.
Source: Data from U.S. Department of Agriculture, Agricultural Research Service, 2012. USDA National Nutrient Database for Standard Reference, Release 25. Nutrient Data Laboratory home page. Available at: http://www.ars.usda.gov/ba/bhnrc/ndl.

What is a suggestion for a vitamin B_6-rich meal or snack?

Lunch: Egg salad sandwich on whole wheat bread and a banana

Total vitamin B_6 content = 0.834 milligrams

Do athletes need vitamin B_6 supplements?

The current research on the athletic performance benefits of vitamin B_6 supplementation is equivocal. Some studies have found marginal or low vitamin B_6 status in physically active individuals.[13,16] When a supplement was provided over several weeks, erythrocyte activity coefficients increased,[16] suggesting that exercise may further decrease vitamin status in active individuals who might already have low intakes of vitamin B_6.[17] Much of the exercise-related research has focused on determining the changes in vitamin B_6 metabolism during training to establish whether additional vitamin B_6 is indicated. Many studies involving short-duration and moderate-intensity exercise have shown an increase in vitamin B_6 in the blood within minutes of the onset of exercise and throughout the exercise bout. B_6 then shows a slow decline after the cessation of exercise.[15,18] An incremental increase during exercise is plausible in theory because of the increased reliance on gluconeogenesis for energy production, thus requiring more vitamin B_6. However, a recent study examining the changes in plasma vitamin B_6 in ultra-marathoners observed the opposite result, with postexercise levels lower than preexercise levels, with a further decline 60 minutes after the completion of the ultra-marathon.[19] More research is warranted to determine the exact changes in vitamin B_6 metabolism during short- and long-duration exercise to establish recommendations for supplementation during training or competition.

Why is vitamin B_{12} important for athletes?

Vitamin B_{12} is also commonly referred to as cobalamin. Adequate intake and absorption of this vitamin are of special concern to older athletes as well as vegetarian and vegan athletes. Vitamin B_{12} plays a role in the health and performance of the nervous and cardiovascular systems, the growth and development of tissues, and energy production. Vitamin B_{12} maintains the integrity of the myelin sheath, which is the protective coating surrounding all nerve fibers. Vitamin B_{12} is critical for folate metabolism, which, in turn, relates to DNA synthesis and tissue growth. Adequate intakes of vitamin B_{12} prevent the onset of pernicious anemia. Vitamin B_{12} is also involved in preparing fatty acid chains to enter the citric acid cycle, thus facilitating energy production.

A health-related task of vitamin B_{12} is the lowering of homocysteine and thus the prevention of heart disease. High levels of homocysteine have recently been accepted as a valid risk factor for cardiovascular disease.[20] Homocysteine is converted to methionine with the coenzyme assistance of vitamin B_{12}, thus lowering blood levels of homocysteine and the risk for disease (see Figure 6.4).

What is the RDA/AI for vitamin B_{12}?

The RDA for vitamin B_{12} is 2.4 micrograms for adults aged 19 to 50 years.[2] Older adults have the same requirement; however, many older individuals have a decreased ability to absorb B_{12}. The synthetic form of B_{12} can be absorbed more readily than food sources for these individuals; therefore, they should focus on incorporating fortified foods and supplements into their daily diet.

What are the complications of vitamin B_{12} deficiency?

Vitamin B_{12} deficiency is caused by either impaired absorption or decreased intake. Because vitamin B_{12} is found naturally only in animal products, individuals following a vegetarian or especially a vegan diet will need to consume fortified foods or take daily supplements to avoid deficiency problems. The liver stores B_{12}, and therefore deficiencies develop gradually over time. Vitamin B_{12} deficiency can result in neurological problems and pernicious anemia. B_{12} is critical for the health of the myelin sheath, so low intake causes the myelin sheath to swell and break down, leading to brain abnormalities and spinal cord degeneration. Pernicious anemia leads to altered red blood cell formation, producing megaloblasts and macrocytes, meaning large, irregular cells. Pernicious anemia may lead to decreased endurance performance, but more research is needed before conclusions can be drawn and recommendations formulated.

In regard to cardiovascular health, a deficiency of vitamin B_{12} can lead to increasing levels of homocysteine and a greater risk for disease. A study conducted by Herrmann et al.[21] found that 25% of study participants, all recreational athletes, had elevated homocysteine levels that were associated with low levels of both vitamin B_{12} and folate. Engaging in physical activity on a regular basis is a negative risk factor for cardiovascular disease. However, efforts to prevent disease through exercise may be negated if daily nutrition and adequate intake of B_{12} are neglected.

What are the symptoms of vitamin B_{12} toxicity?

Because there are no recognized detrimental effects from high doses of B_{12}, an upper limit has not been set.

Which foods are rich in vitamin B_{12}?

Vitamin B_{12} is naturally found only in animal products such as meats, dairy products, and eggs (see Figure 6.6). For vegetarians and vegans, fortified foods include breakfast cereals, soy milks, and other soy-based products.

VITAMIN B_{12}

Daily Value = 6 µg
RDA = 2.4 µg (males/females)

	Food	Serving	Vitamin B_{12}
	Exceptionally good sources		
High: 20% DV or more	Clams, cooked	85 g (3 oz)	84.1 µg
	Beef liver, cooked	85 g (3 oz)	71 µg
	Oysters, cooked	85 g (3 oz)	29.8 µg
	Chicken liver, cooked	85 g (3 oz)	18.0 µg
	Herring, cooked	85 g (3 oz)	11.2 µg
	Crab, Alaska King, cooked	85 g (3 oz)	9.8 µg
	Crab, blue, cooked	85 g (3 oz)	6.2 µg
	Wheat bran flakes cereal	30 g (3/4 cup)	6.2 µg
	All Bran cereal	30 g (1/2 cup)	6.0 µg
	Sardines, canned, solids + bones	55 g (2 oz)	4.9 µg
	Salmon, cooked	85 g (3 oz)	2.6 µg
	Lobster, cooked	85 g (3 oz)	2.6 µg
	Beef, ground, extra lean, cooked	85 g (3 oz)	2.2 µg
	Beef, T-bone steak, cooked	85 g (3 oz)	1.9 µg
	Tuna, canned	55 g (2 oz)	1.7 µg
	Yogurt, plain, nonfat	225 g (8-oz container)	1.4 µg
	Shrimp, cooked	85 g (3 oz)	1.3 µg
	Yogurt, plain, low-fat	225 g (8-oz container)	1.3 µg
	Halibut, cooked	85 g (3 oz)	1.2 µg
Good: 10–19% DV	Milk, 2% milkfat	240 mL (1 cup)	1.1 µg
	Milk, whole 3.25% milkfat	240 mL (1 cup)	1.1 µg
	Squid, cooked	85 g (3 oz)	1.0 µg
	Milk, 1% milkfat	240 mL (1 cup)	1.0 µg
	Milk, nonfat	240 mL (1 cup)	0.9 µg
	Cod, cooked	85 g (3 oz)	0.9 µg
	Frankfurter, beef	55 g (1 each)	0.9 µg
	Bologna, beef	55 g (2 slices)	0.8 µg
	Cottage cheese, 2% milkfat	110 g (~1/2 cup)	0.7 µg
	Pork, loin chops, lean only, cooked	85 g (3 oz)	0.6 µg

Figure 6.6 Food sources of vitamin B_{12}. Vitamin B_{12} is found naturally only in foods of animal origin such as liver, meats, and milk. Some cereals are fortified with vitamin B_{12}. Note: The DV for vitamin B_{12} is substantially higher than the current RDA of 2.4 micrograms for males and females age 14 and older.

Source: Data from U.S. Department of Agriculture, Agricultural Research Service, 2012. USDA National Nutrient Database for Standard Reference, Release 25. Nutrient Data Laboratory home page. Available at: http://www.ars.usda.gov/ba/bhnrc/ndl.

What is a suggestion for a vitamin B_{12}-rich meal or snack?

Dinner: 3 oz slice of meatloaf with ¾ cup mashed potatoes, 1¼ cups salad, and 12 oz skim milk
Total vitamin B_{12} content = 2.45 micrograms

Do athletes need vitamin B_{12} supplements?

As mentioned previously, vegetarian or vegan athletes may need supplemental B_{12} from fortified vegetarian foods, soy products, or multivitamins. Masters or elderly athletes may also need B_{12} supplements if they have atrophic gastritis and/or low levels of intrinsic factor. Those with diagnosed pernicious anemia will have enhanced performance after consuming higher doses of B_{12}. However, studies following individuals without pernicious anemia who are consuming large doses of vitamin B_{12} through supplements or vitamin B_{12}-rich foods have shown no effect on endurance, VO_2max, or body building. Therefore, a healthy athlete consuming a balanced diet may not benefit from vitamin B_{12} supplements.

Why is folate important for athletes?

The terms *folate* and *folic acid* are often used interchangeably, referring to the same nutrient. However, folate is the form of this vitamin found in whole foods, whereas folic acid is the most stable form or derivative of folate and is therefore used in supplements and fortified foods. The significance of folate for health and well-being is apparent at the moment of conception. Folate is critical for DNA synthesis and cell division, thus playing an important role in the growth and development of a fetus. Adequate folate intake has been recognized as a key in the prevention of neural-tube defects during pregnancy. It is critical for a woman to be consuming enough folate at the time of conception, because most neural-tube defects occur within the first month after conception. This discovery was the driving force behind the 1998 Food and Nutrition Board mandate to fortify grains in the United States with folic acid.

Because of its role in cellular development throughout the body, folate also aids in the maturation of red blood cells and the repair of tissues. Adequate folate intake prevents the development of megaloblastic, macrocytic anemia. This type of anemia is

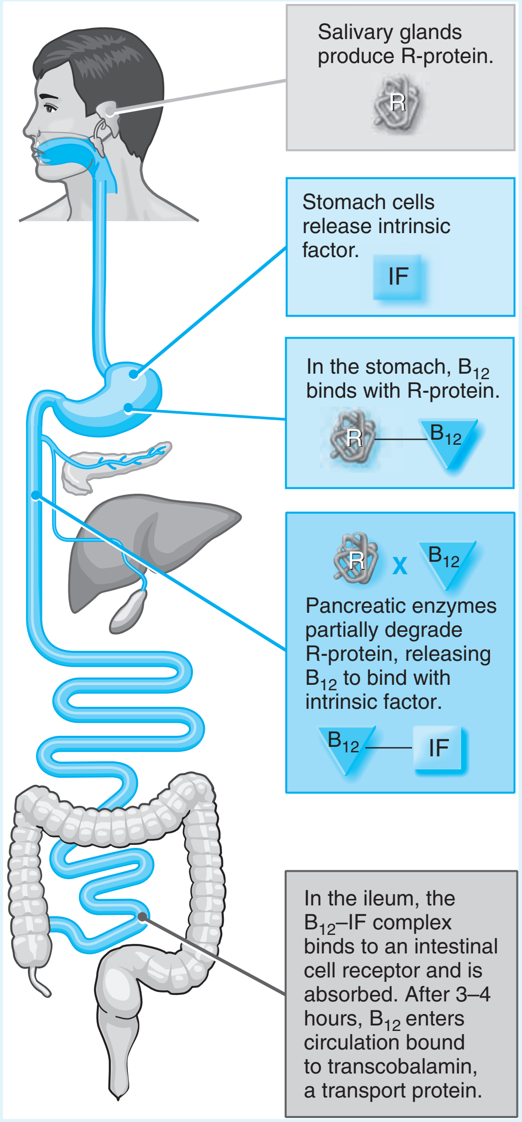
Fortifying
Your Nutrition Knowledge

Vitamin B_{12} Absorption

Vitamin B_{12} has a complex progression from ingestion to absorption. For elderly or ill individuals, several steps in the digestion pathway can cause suboptimal absorption:

1. R-protein is produced by the salivary glands in the mouth and travels unconnected to vitamin B_{12} to the stomach.
2. In the stomach, R-protein binds with vitamin B_{12} as a protective mechanism as the complex travels to the small intestine. Intrinsic factor is secreted by the parietal cells of the stomach and travels with the B_{12}–R-protein complex to the small intestine. For elderly individuals, the parietal cells become less functional, producing less intrinsic factor, thus affecting vitamin B_{12} absorption in the small intestine.
3. Pancreatic enzymes cleave B_{12} from the R-protein in the small intestine.
4. B_{12} then binds to intrinsic factor and travels to the ileum of the small intestine, where it binds to the brush border and is absorbed and transported throughout the body. For individuals who suffer from chronic diarrhea or sloughing of the brush border because of age, illness, or medications, vitamin B_{12} absorption will be diminished.

Absorption of vitamin B_{12} is a complex process that involves many factors and sites in the GI tract. Defects in this process, especially a lack of intrinsic factor, impair absorption and can result in deficiency.



also a result of vitamin B_{12} deficiency; therefore, it is critical to determine which nutrient is the cause of the anemia to establish the appropriate method of treatment. If anemia develops, energy levels for training and competition may suffer. Folate also facilitates muscle tissue repair after strenuous exercise, aiding in recovery.

In addition, folate has recently gained recognition in the area of cardiovascular health. Folate helps to lower levels of homocysteine in the blood, thus potentially lowering the risk for heart disease.

What is the RDA/AI for folate?

The RDA for folate is 400 micrograms per day for adult males and females.[2] The RDA is expressed in Dietary Folate Equivalents (DFE). One DFE equals 1 microgram of folate from food, 0.6 micrograms of folic acid in fortified foods, or 0.5 micrograms of folic acid in supplements taken on an empty stomach.

What are the complications of folate deficiency?
Because of folate's role in basic cell development and division, deficiency of this vitamin affects many components of health and performance. During pregnancy and fetal development, if the mother consumes suboptimal levels of folate, the risk of neural-tube defects increases considerably. The lack of folate causes incomplete and altered neural-tube development within the spine, leading to conditions such as spina bifida. Low folate causes a change in DNA, affecting various cells such as those in the lining of the intestines and causing absorption problems and chronic diarrhea. White blood cell development can also be impaired, contributing to poor immune function.

Insufficient intake of folate can lead to a type of anemia known as megaloblastic anemia. Because of an altered DNA synthesis, division of red blood cells is not normal, producing large, abnormal red blood cells with short life spans. These abnormal cells have a decreased oxygen-carrying capacity, leading to symptoms of anemia such as fatigue, weakness, irritability, and disturbed sleep. Because deficiencies in both B_{12} and folate can cause anemia, it is important to pay attention to all symptoms to prevent misdiagnosis and further complications. For example, if a B_{12} deficiency is mistaken for a folate deficiency, higher levels of folate will repair the megaloblastic anemia, but other neurological problems will continue to develop as a result of the low vitamin B_{12} intake. Low folate intake may also increase the risk for heart disease by allowing homocysteine levels to rise. Folate works with other water-soluble vitamins, B_6 and B_{12}, to reduce homocysteine levels in the blood.

What are the symptoms of folate toxicity?
Folate toxicity is rare because ingesting excessive levels of folate is difficult to do through consumption of foods; in addition, excess folate is excreted in the urine. However, an UL has been established for adults at 1000 micrograms. The main reason for the UL is that high levels of folate can hide symptoms of vitamin B_{12} deficiency. Because athletes have an increased risk for vitamin B_{12} deficiency, observing the UL of folate will help prevent misdiagnosis and resulting complications.

Which foods are rich in folate?
When thinking of folate, think "foliage" or plant foods. Folate-rich foods include many plant-based products, such as dark green leafy vegetables, strawberries, oranges, legumes, nuts, brewer's yeast, and fortified grains (see Figure 6.7). Folate fortification of grains and flours was mandated in 1996 and went into effect in 1998 in the United States as a result of a plethora of research showing the importance of adequate folate intake in reducing the incidence of neural-tube defects. Fortification is

FOLATE

Daily Value = 400 μg
RDA = 400 μg (males/females)

Exceptionally good sources			
	Chicken liver, cooked	85 g (3 oz)	491 μg
	Wheat bran flakes cereal	30 g (1 cup)	417 μg
	Product 19 cereal	30 g (1 cup)	400 μg
High: 20% DV or more	All Bran cereal	30 g (1/2 cup)	393 μg
	Beef liver, cooked	85 g (3 oz)	221 μg
	Cheerios cereal	30 g (1 cup)	200 μg
	Spinach, raw	85 g (~3 cups)	165 μg
	Lentils, cooked	90 g (~1/2 cup)	163 μg
	Pinto beans, cooked	90 g (~1/2 cup)	155 μg
	Black beans, cooked	90 g (~1/2 cup)	134 μg
	Asparagus, cooked	85 g (~1/2 cup)	127 μg
	Spinach, cooked	85 g (~1/2 cup)	124 μg
	Romaine lettuce, raw	85 g (~1 1/2 cups)	116 μg
	Black-eyed peas, cooked	90 g (~1/2 cup)	114 μg
	Corn flakes cereal	30 g (1 cup)	110 μg
	Spaghetti, enriched, cooked	140 g (1 cup)	108 μg
	Oatmeal, instant, fortified, cooked	1 cup	101 μg
	Turnip greens, cooked	85 g (~2/3 cup)	100 μg
	Soybeans, cooked	90 g (~1/2 cup)	100 μg
	Broccoli, cooked	85 g (~1/2 cup)	92 μg
	Rice, white, enriched, cooked	140 g (~3/4 cup)	81 μg
Good: 10–19% DV	Collards, cooked	85 g (~1/2 cup)	79 μg
	Sunflower seeds	30 g (~ 1 oz)	71 μg
	Beets, cooked	85 g (~1/2 cup)	68 μg
	Mustard greens, cooked	85 g (~2/3 cup)	62 μg
	White bread, enriched	50 g (2 slices)	56 μg
	Tomato juice, canned	240 mL (1 cup)	49 μg
	Orange juice, chilled	240 mL (1 cup)	45 μg
	Crab, Alaska King, cooked	85 g (3 oz)	43 μg
	Artichokes, cooked	85 g (~1/2 cup)	43 μg
	Kidney beans, canned	85 g (~1/2 cup)	42 μg
	Wheat germ	15 g (1/4 cup)	42 μg
	Orange, fresh	140 g (1 medium)	42 μg

Figure 6.7 Food sources of folate. Good sources of folate are a diverse collection of foods, including liver, legumes, leafy greens, and orange juice. Enriched grains and fortified cereals are other ways to include folic acid in the diet.
Source: Data from U.S. Department of Agriculture, Agricultural Research Service, 2012. USDA National Nutrient Database for Standard Reference, Release 25. Nutrient Data Laboratory home page. Available at: http://www.ars.usda.gov/ba/bhnrc/ndl.

estimated to increase the average American's intake of folic acid by approximately 100 micrograms of folic acid per day. This increase in intake was designed to help Americans achieve the RDA of 400 micrograms per day, while not exceeding the upper limit of 1000 micrograms. For more information on folic acid fortification, visit the FDA's website at www.fda.gov.

What is a suggestion for a folate-rich meal?
Dinner: Black-eyed peas with Chinese greens or Slow Cooker Navy Bean Soup (see **Training Tables 6.1 and 6.2**)
Total folate content (per serving) = 407 micrograms for Black-Eyed Peas with Chinese Greens and 175 micrograms for Slow Cooker Navy Bean Soup.

Do athletes need folate supplements?
Consuming a variety of plant-based, folate-rich foods should prevent problems such as anemia. Fortified grains should also be included as a significant source of folate for meeting the RDA. A multivitamin can be used for extra insurance of meeting needs. To date, there have been no studies suggesting an increased exercise capacity by consuming extra folate.

Training Table 6.1: Black-Eyed Peas with Chinese Greens

2 cups brown rice
2 tbsp minced ginger root
3 cloves of garlic
1 tbsp peanut oil
1 tbsp sesame oil
2 lbs bok choy or napa cabbage
3 15-oz cans of black-eyed peas
2 tbsp soy sauce

Bring 2 cups of water to a boil. Add the brown rice and cook at a simmer for 30 to 40 minutes until all the water is absorbed. In the meantime, sauté the ginger and garlic in the peanut and sesame oils in a Dutch oven for 5 to 10 minutes over medium-high heat. Cut the bok choy or cabbage into ½-inch strips and add to the ginger and garlic; cook for 5 to 7 minutes. Add the black-eyed peas and soy sauce, and cook for an additional 5 minutes.

Serve over brown rice.

Serving Size: 2 cups (Recipe makes 4–6 servings)

Calories: 540 kcals

Protein: 26 grams

Carbohydrate: 95 grams

Fat: 8 grams

Training Table 6.2: Slow Cooker Navy Bean Soup

1 lb dry navy beans
4 cups vegetable broth
4 cups water
1 cup carrots, chopped
3 celery stalks, chopped
2 garlic cloves, minced
1 cup onions, chopped
1 4-oz can chopped green chiles
1 15-oz can diced tomatoes

Rinse navy beans and put into large pot. Cover beans with 3 inches of water and soak overnight.

Rinse soaked beans and place in slow cooker. Add remaining ingredients and cook on low for 10 hours.

Serving size: 1.5 cups (Recipe makes 10 servings)

Calories: 186 kcals

Protein: 11 grams

Carbohydrate: 34 grams

Fat: 1 grams

Why is biotin important for athletes?

In the 1920s three similar compounds—bios II, vitamin H, and coenzyme R—were all found to be beneficial to the body. With further investigation, it was recognized that all three compounds were the same nutrient—biotin. Biotin plays a role in synthesizing DNA for healthy cell development and energy production for endurance activities. Biotin is a cofactor for several carboxylase enzymes involved in the metabolism of carbohydrates, proteins, and fats. Biotin also helps produce energy by facilitating gluconeogenesis.

What is the RDA/AI for biotin?
Currently, very little research exists on the biotin requirements for a healthy adult. Therefore, no RDA has been set. The AI for adults is 30 micrograms per day.[2]

What are the complications of biotin deficiency?
Biotin deficiency is rare because so little is required. A few cases of biotin deficiency have been observed in those with a prolonged consumption of raw egg whites and those dependent upon parenteral nutrition without biotin supplementation.[22] Some documented signs and symptoms of biotin deficiency include fatigue, depression, nausea, dermatitis, and muscular pains.

What are the symptoms of biotin toxicity?
No physical or mental signs or symptoms of biotin toxicity have been documented. Biotin appears to be safe even at high levels, so no upper limit has been set.

Which foods are rich in biotin?
Biotin is found in a wide range of different foods. Legumes, cheese, egg yolks, nuts, and green leafy vegetables are all good sources of biotin. Raw egg whites will bind to biotin and may contribute to biotin deficiency if consumed on a regular basis. Cooking of egg whites alleviates this problem and also decreases the risk of sickness caused by foodborne pathogens. Biotin content has not been determined for most foods, and therefore is not listed on most food composition charts.

What is a suggestion for a biotin-rich meal or snack?
Breakfast: 3 scrambled eggs with ¼ cup shredded cheddar cheese and 2 tbsp peanut butter on 1 slice of whole wheat toast
Total biotin content = 57 micrograms

Do athletes need biotin supplements?
Very little research has been conducted on biotin and exercise performance. Because no toxic level has been detected, supplemental biotin may not be harmful to health or performance, but it also may not be necessary.

PANTOTHENIC ACID

Daily Value = 10 mg
AI = 5 mg (males/females)

High: 20% DV or more	Beef liver, cooked	85 g (3 oz)	6.0 mg
	Chicken liver, cooked	85 g (3 oz)	5.6 mg
	Sunflower seeds	30 g (~1 oz)	2.1 mg
Good: 10–19% DV	Mushrooms, cooked	85 g (~½ cup)	1.8 mg
	Yogurt, plain, nonfat	225 g (1 8-oz container)	1.4 mg
	Yogurt, plain, low-fat	225 g (1 8-oz container)	1.3 mg
	Turkey, dark meat, cooked	85 g (3 oz)	1.1 mg
	Chicken, dark meat, cooked	85 g (3 oz)	1.0 mg

Figure 6.8 Food sources of pantothenic acid. Pantothenic acid is found widely in foods, but it is abundant in only a few sources, such as liver. Note: The DV for pantothenic acid is higher than the current AI of 5 milligrams for males and females age 19 and older.
Source: Data from U.S. Department of Agriculture, Agricultural Research Service, 2012. USDA National Nutrient Database for Standard Reference, Release 25. Nutrient Data Laboratory home page. Available at: http://www.ars.usda.gov/ba/bhnrc/ndl.

Why is pantothenic acid important for athletes?

Because of the role pantothenic acid plays in energy metabolism, there is little question that it is important to athletes. Specifically, pantothenic acid is a component of coenzyme A, a molecule critical for the passage of metabolic intermediates from fat, carbohydrate, and protein metabolism into the citric acid cycle. The citric acid cycle is one of the major metabolic pathways involved in the aerobic production of ATP. The key question is whether pantothenic acid supplementation will improve athletic performance. Limited research has been conducted to date; however, pantothenic acid supplementation has not been shown to be beneficial to athletes.[23,24]

What is the RDA/AI for pantothenic acid?
No RDA has been set for pantothenic acid. The AI is set at 5 milligrams per day for adults aged 19 to 50 years.[2]

What are the complications of pantothenic acid deficiency?
Fatigue, sleep disturbances, impaired coordination, nausea, hypoglycemia, and muscle cramps can signal low levels of pantothenic acid. However, deficiencies are very rare.

What are the symptoms of pantothenic acid toxicity?
There appear to be no risks with high intake of pantothenic acid; therefore, no upper limit has been set.

Which foods are rich in pantothenic acid?
Pantothenic acid can be found in beef, poultry, fish, whole grains, dairy products, legumes, potatoes, oats, and tomatoes (see Figure 6.8). Consuming fresh and whole foods is especially beneficial in regard to pantothenic acid because freezing, canning, processing, and refining foods decrease the foods' pantothenic acid content considerably.

What is a suggestion for a pantothenic acid–rich meal or snack?
Lunch: Baked potato topped with ¾ cup garbanzo beans, ¼ cup salsa, and 2 tbsp melted cheese, and an 8 oz glass of skim milk
Total pantothenic acid content = 2.4 milligrams

Do athletes need pantothenic acid supplements?
Because pantothenic acid is widespread in a balanced diet, and deficiencies are so rare, supplementation for

athletes does not appear to be required. In addition, the existing research does not provide enough information to warrant supplementation for enhanced athletic performance.

Why is choline important for athletes?

Choline is a vitamin-like compound, but it is not considered a B vitamin. Similar to biotin, choline is not well researched, and therefore limited information is available on its role in health and sport performance. Choline is involved in the formation of the neurotransmitter acetylcholine, which is involved in muscle activation. In theory, higher intakes of choline would maintain higher blood levels of the nutrient and increased levels of acetylcholine in the nerve endings, thus preventing muscle fatigue and/or failure. More research is needed to evaluate this theory, however. Choline has also been shown to help maintain the structural integrity of cell membranes.

What is the RDA/AI for choline?

Because of the lack of research on choline, an RDA has not been set. The AI has been set at 550 and 425 milligrams per day for men and women, respectively.[2]

What are the complications of choline deficiency?

The risk for choline deficiency is low because it is found in a wide variety of foods. The human body also makes choline endogenously, further decreasing the risk for deficiency.

What are the symptoms of choline toxicity?

The signs and symptoms of choline toxicity include low blood pressure, diarrhea, and a fishy body odor. The upper limit for choline is set at 3500 milligrams per day, many times the AI level.

Which foods are rich in choline?

Well-balanced diets provide sufficient levels of choline. Some of the richest sources of choline include lecithin, egg yolks, liver, nuts, milk, wheat germ, cauliflower, and soybeans. Choline can be produced in the body from the amino acid methionine. Therefore, ingesting protein-rich foods, which provide methionine, can indirectly contribute to daily choline needs. Very few foods have been tested to determine choline levels, making food value databases containing choline unavailable.

What is a suggestion for a choline-rich meal or snack?

Side dish for dinner: Roasted broccoli and cauliflower (see **Training Table 6.3**). Nutrient databases for choline are incomplete and therefore a nutrient analysis is not available.

Training Table 6.3: Roasted Broccoli and Cauliflower

½ lb broccoli
½ lb cauliflower
cooking spray
dried basil, oregano, and black pepper

Preheat oven to 500°F. Chop broccoli and cauliflower into 2-inch pieces and spread evenly on a cookie sheet coated with cooking spray. Spray more cooking spray on top of the vegetables and sprinkle with dried basil, oregano, and black pepper. Bake for 10 to 15 minutes and serve as a side dish to a favorite dinner.

Serving Size: 1½ cups (Recipe makes 2 servings)

Calories: 67 kcals

Protein: 5 grams

Carbohydrate: 13 grams

Fat: 1 gram

Do athletes need choline supplements?

The current research results are equivocal for endurance sports as well as power and strength sports. A study by Hongu and Sachan[25] reported that choline supplements given to healthy women promoted carnitine conservation and favored incomplete oxidation of fatty acids and disposal of fatty acid carbons in the urine. Earlier studies suggest that this scenario, induced by the choline supplements, might reduce fat mass and increase fat oxidation during exercise.[26,27] However, more research is needed to clarify choline's role in physical activity and whether supplementation would be beneficial to athletes.

Why is vitamin C important for athletes?

Vitamin C is also commonly referred to as ascorbic acid or ascorbate. It has received great attention in the last decade for its antioxidant properties. Vitamin C plays several roles in promoting general health. It is critical for the formation of collagen, which is a fibrous protein found in connective tissues of the body such as tendons, ligaments, cartilage, bones, and teeth. Collagen synthesis is also important in wound healing and the formation of scar tissue. Vitamin C plays a role in a healthy immune system

carnitine A compound that transports fatty acids from the cytosol into the mitochondria, where they undergo beta-oxidation.

antioxidants Compounds that protect the body from highly reactive molecules known as free radicals.

collagen A fibrous protein found in connective tissues of the body, such as tendons, ligaments, cartilage, bones, and teeth.

and enhances iron absorption of nonheme iron, thus protecting the body against iron-deficiency anemia.

Cardiovascular research has indicated that vitamin C's role as an antioxidant seems to be protective against heart disease, especially by preventing the oxidation of LDL, which can lead to atherosclerosis. Atherosclerosis is the progressive narrowing of the lumens of arteries caused by fatty deposits on their interior walls. Over time these fatty plaques can block blood supply to vital tissues, causing poor delivery of oxygen; with complete blockage, cell death occurs.

Vitamin C supplementation has recently been promoted to athletes as a potent antioxidant, helping to combat the oxidative damage that can occur during intense exercise. This potential function of vitamin C needs further investigation because current research is contradictory (see the section "Which vitamins or compounds have antioxidant properties?" later in this chapter). Vitamin C also aids in the formation of various hormones and in the production of neurotransmitters such as epinephrine.

What is the RDA/AI for vitamin C?

The RDA for males is 90 milligrams per day and for females is 75 milligrams per day.[28] If an individual smokes regularly, which increases oxidative stress and the metabolic turnover of vitamin C, the RDA increases by 35 milligrams per day.[28]

What are the complications of vitamin C deficiency?

The first signs of vitamin C deficiency are swollen gums and fatigue. If left untreated, the deficiency disease scurvy can develop, causing a degeneration of the skin, teeth, and blood vessels resulting from low collagen production. The physical manifestations of scurvy include bleeding gums, impaired wound healing, and weakness. However, deficiencies in the United States are rare because fruits and vegetables that contain high levels of vitamin C are available year-round. As a protective mechanism, the body stores several grams of vitamin C in case of short periods of low vitamin C intake.

What are the symptoms of vitamin C toxicity?

Vitamin C is a water-soluble vitamin, so it is relatively nontoxic. Intakes of greater than 1500 milligrams a day are not well absorbed, and excesses are excreted in the urine. However, at intake levels greater than the established upper limit of 2000 milligrams daily, side effects can include nausea, abdominal cramps, diarrhea, and nosebleeds. Long-term megadoses of vitamin C can also contribute to kidney stones, decrease the absorption of other nutrients, and may increase the risk for heart disease.

Which foods are rich in vitamin C?

The richest sources of vitamin C include citrus fruits and their juices, tomatoes and tomato juice, potatoes, green peppers, green leafy vegetables, kiwi, and cabbage (see Figure 6.9).

VITAMIN C

Daily Value = 60 mg
RDA = 90 mg (males), 75 mg (females)

DV level	Food	Serving	Vitamin C
Exceptionally good sources	Strawberries, fresh	140 g (~1 cup)	82.3 mg
	Orange juice, chilled	240 mL (1 cup)	81.9 mg
	Orange, fresh	140 g (1 medium)	74.5 mg
	Wheat bran flakes	30 g (3/4 cup)	62.1 mg
High: 20% DV or more	Cantaloupe, fresh	140 g (1/4 medium melon)	51.4 mg
	Tomato juice, canned	240 mL (1 cup)	44.5 mg
	Mango, fresh	140 g (~3/4 cup)	38.8 mg
	Cauliflower, cooked	85 g (~3/4 cup)	37.7 mg
	Broccoli, cooked	85 g (~1/2 cup)	35.7 mg
	Spinach, raw	85 g (~3 cups)	23.9 mg
	Pineapple, fresh	140 g (~1 cup)	23.7 mg
	Watermelon, fresh	280 g (1/16 melon)	22.7 mg
	Sweet potato, cooked	110 g (1 small)	21.6 mg
	Mustard greens, cooked	85 g (~2/3 cup)	21.5 mg
	Romaine lettuce, raw	85 g (~1 1/2 cups)	20.4 mg
	Beef liver, cooked	85 g (3 oz)	19.6 mg
	Clams, cooked	85 g (3 oz)	18.8 mg
	Cabbage, cooked	85 g (~1/2 cup)	17.1 mg
	Collards, cooked	85 g (~1/2 cup)	15.5 mg
	Soybeans, cooked	90 g (~1/2 cup)	15.3 mg
	Swiss chard, cooked	85 g (~1/2 cup)	15.3 mg
	Okra, cooked	85 g (~1/2 cup)	13.9 mg
	Blueberries, fresh	140 g (~3/4 cup)	13.6 mg
	Banana, fresh	140 g (1 9" banana)	12.2 mg
Good: 10–19% DV	Potato, baked	110 g (1 small)	10.6 mg
	Peach, fresh	140 g (2 small)	9.2 mg
	Acorn squash, cooked	85 g (~1/2 cup)	9.2 mg
	Spinach, cooked	85 g (~1/2 cup)	8.3 mg
	Green beans, cooked	85 g (~3/4 cup)	8.2 mg
	Asparagus, cooked	85 g (~1/2 cup)	6.5 mg
	Corn flakes cereal	30 g (1 cup)	6.4 mg
	Cheerios cereal	30 g (1 cup)	6.0 mg

Figure 6.9 Food sources of vitamin C. Vitamin C is found mainly in fruits and vegetables. Although citrus fruits are notoriously good sources, many other popular fruits and vegetables are rich in vitamin C. Note: The DV for vitamin C is lower than the current RDA of 90 milligrams and 75 milligrams for males and females, respectively, age 19 and older.

Source: Data from U.S. Department of Agriculture, Agricultural Research Service, 2012. USDA National Nutrient Database for Standard Reference, Release 25. Nutrient Data Laboratory home page. Available at: http://www.ars.usda.gov/ba/bhnrc/ndl.

What is a suggestion for a vitamin C–rich meal or snack?
Snack: Fruit salad made with 1 orange, 2 kiwis, and 3/4 cup cantaloupe
Total vitamin C content = 269 milligrams

Do athletes need vitamin C supplements?
Some research supports the notion that athletes need higher levels of vitamin C than the RDA because of the oxidative stress of training and competition. Other research shows little or no benefit of vitamin C supplementation on athletic performance. It appears that in athletes with adequate vitamin C status, supplementation with vitamin C does not enhance exercise performance.[29] The U.S. Olympic Committee has approved vitamin C supplements at levels of 250–1000 milligrams per day. Athletes can easily obtain 200–500 milligrams of vitamin C per day through a well-balanced diet including plenty of fruits and vegetables. Supplements used to achieve higher doses of vitamin C should be consumed with caution. As mentioned previously, vitamin C aids in iron absorption. For athletes who are low in iron, this action can be beneficial; however, for those who are more susceptible to hemochromatosis, which is a disorder that results in the excessive absorption of iron, vitamin C supplementation is not recommended and may exacerbate symptoms.

gaining the performance edge

Water-soluble vitamins include the B vitamins, vitamin C, and choline. Each vitamin has its own function in the body, DRI, complications of deficiency, symptoms of toxicity, unique food sources, and requirements for supplementation. All water-soluble vitamins are critical to health, and therefore a variety of food sources should be consumed daily to meet the recommended levels for each nutrient.

Food for Thought 6.1

Importance of Vitamin Intake for Athletes: Water-Soluble Vitamins

Review the recommendations, food sources, and significance of water-soluble vitamins for athletes.

What are the fat-soluble vitamins?

Vitamins A, D, E, and K make up the fat-soluble vitamins. These vitamins require small amounts of dietary fat to help the body absorb, transport, and utilize them. Unlike water-soluble vitamins, these vitamins can be stored in the body, primarily in fat tissues and the liver, but also in other organ tissues in smaller amounts. As a result, the levels of fat-soluble vitamins in the body can build over time, potentially causing toxicity. Dietary intake from food rarely causes toxic buildup of the fat-soluble vitamins, but the risk for accumulating toxic levels in the body increases with the use of supplements containing high levels of these vitamins.

retinoids A class of compounds that have chemical structures similar to vitamin A. Retinol, retinal, and retinoic acid are three active forms of vitamin A that belong to the retinoid family of compounds.

Why is vitamin A important for athletes?

Vitamin A has numerous functions in the body and is found in three different forms: retinol, retinal, and retinoic acid. These three forms are collectively called **retinoids**. One of the crucial functions of vitamin A in the body is its role in vision (see Figure 6.10). Retinol is transported in the blood to the retina in the eye, where it is converted to retinal. Retinal combines with the protein opsin to form the pigment rhodopsin, which allows humans to see black-and-white images. Iodopsin, another pigment that involves retinal, allows humans to see color images. Light entering the eye stimulates a process of separating retinal from the opsin and iodopsin, causing the proteins to change shape. The change in protein shape stimulates optical receptors in the retina that send electrical impulses to the brain, which, in turn, enables sight. When vitamin A is deficient, blindness can occur.

Vitamin A also functions in cell differentiation, the process by which stem cells (i.e., cells that possess the capability of dividing and forming any body tissue) develop into specialized cells with specific functions within the body. For example, vitamin A is very important in the differentiation of epithelial cells, which are found throughout the body and form tissues such as the skin and mucous membranes. Epithelial cells also form the linings of internal organs and passageways of the digestive, respiratory, and circulatory systems. Vitamin A actually activates specific genes within the stem cell nuclei that initiate the differentiation of the appropriate tissue type. Adequate vitamin A is essential for athletes to help repair those tissues that may be injured during sporting events. Vitamin A also appears to have a role in immune function by helping to maintain the skin and mucous membranes (i.e., the epithelial tissues), which act as barriers to infection by bacteria and other pathogens. In fact, the maintenance of epithelial tissues in preventing infection is so

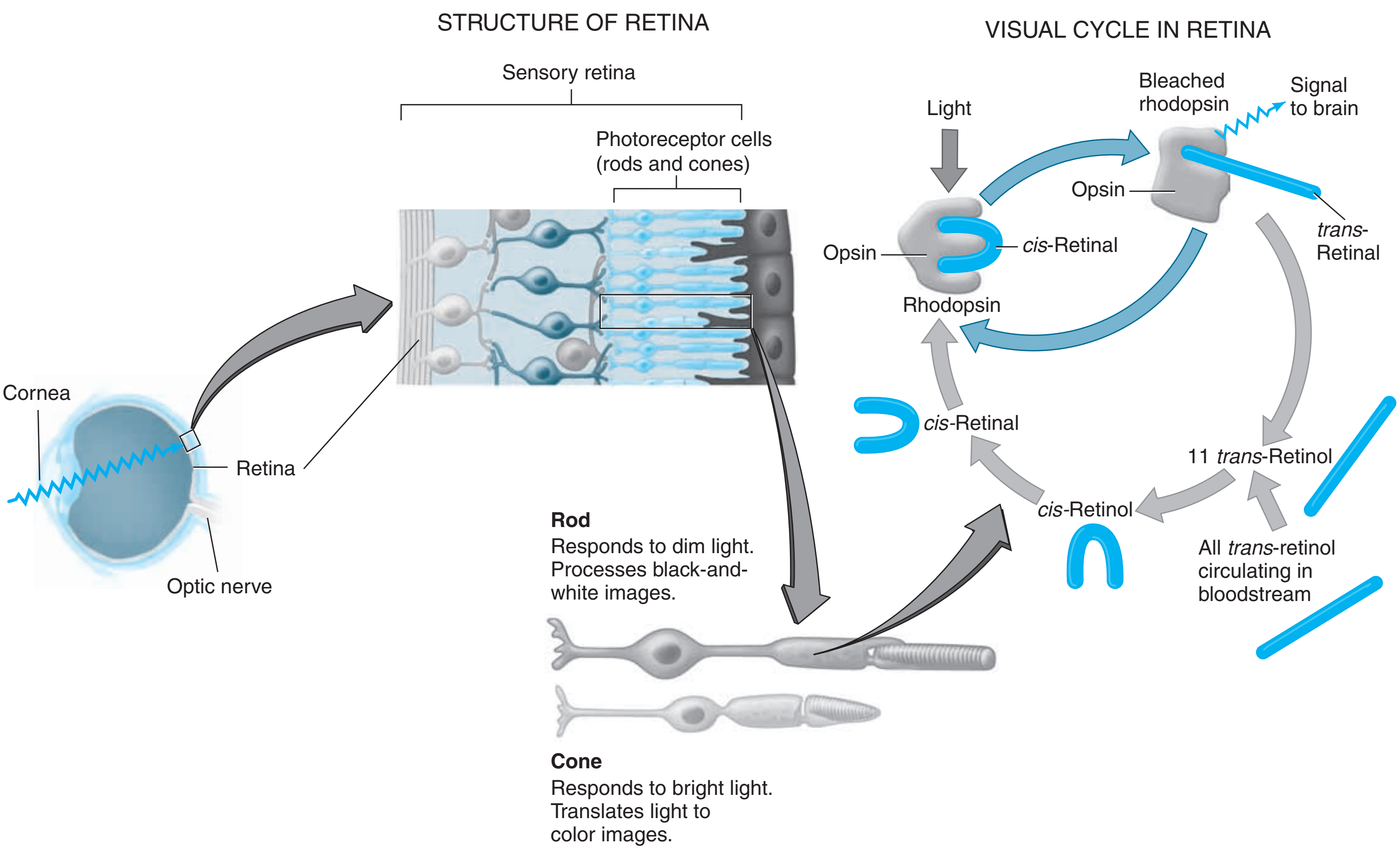


Figure 6.10 Vitamin A and the visual cycle. Rhodopsin is the combination of the protein opsin and vitamin A (retinal). When stimulated by light, opsin changes shape, and vitamin A changes from its bent cis form to a straighter trans form. This sends a signal to the brain, allowing images to be seen in black and white. A similar process using a different protein called iodopsin provides color.

important that vitamin A has been labeled as the "anti-infection" vitamin. Vitamin A also appears to play a role in bone formation and the maintenance of reproductive health. Finally, vitamin A has shown some promise as an antioxidant that may help prevent cancer and certain chronic diseases. For more information regarding the antioxidant role of vitamin A, see the section "Which vitamins or compounds have antioxidant properties?" later in this chapter.

What is the RDA/AI for vitamin A?

Vitamin A can be consumed in the diet from animal sources as retinoids or from plant sources as **carotenoids**. The RDA for vitamin A reflects recommendations based on typical consumption of both plant (carotenoid) and animal (retinoid) sources. However, similar amounts of dietary retinoids and dietary carotenoids do not provide similar amounts of vitamin A. Carotenoids are less biologically active than are retinoids, and therefore greater amounts need to be consumed to meet daily requirements. Because of this difference, the scientific community developed a standardized measurement that can be used for both carotenoid and retinoid consumption in the diet. This standard is the **retinol activity equivalent (RAE)**. One RAE is the amount of a given form of vitamin A equal to the activity of 1 microgram of retinol (see Figure 6.11). The RDA for vitamin A for adult males is 900 micrograms RAE and for adult females is 700 micrograms RAE.[30] Although carotenoids may be slightly lacking in their ability to convert to vitamin A, their overall contribution to physical health is expansive. Carotenoids are discussed in more detail in the next section.

Vitamin A content is often expressed in another measurement called **International Units (IU)**. This measure is

carotenoids A class of colorful phytochemicals that give plants and their fruit the deep colors of orange, red, and yellow. There are hundreds of different carotenoids; however, the ones most identified as vital to health include alpha- and beta-carotene, lycopene, lutein, zeaxanthin, and cryptoxanthin.

retinol activity equivalent (RAE) A unit of measure of the vitamin A content in foods. One RAE equals 1 microgram of retinol.

international units (IU) An outdated system used to measure vitamin activity.

1 retinol activity equivalent (RAE) = 1 μg retinol
= 2 μg supplemental beta-carotene
= 12 μg dietary beta-carotene
= 24 μg dietary carotenoids

Figure 6.11 Retinol equivalents conversion. Retinol activity equivalent (RAE) is a unit of measurement for the vitamin A content of a food. One RAE equals 1 microgram of retinol.

outdated and does not accurately take into consideration bioavailability or absorptive efficiency of the carotenoids. Nonetheless, IU is often the way vitamin A is expressed on the labels of vitamin supplements. When using IU, the recommended intake is 5000 IU daily.

What are the complications of vitamin A deficiency?

Deficiency of vitamin A is rare in the United States, but it does exist in many countries where general malnutrition is found. Blindness is the most common and devastating result of deficiency. Night blindness is often an early symptom of vitamin A deficiency. Early treatment with supplemental vitamin A can reverse these symptoms and prevent further damage to the retina. The skin can develop hyperkeratosis from lack of vitamin A. Hyperkeratosis is caused by the overproduction of the protein keratin, which plugs skin follicles, thickens the skin surface, and causes it to become bumpy and scaly. Other epithelial cells are also affected. The mucous-producing cells may not secrete mucus, thus causing dryness in the mucous membranes of the mouth, intestinal tract, female genital tract, male seminal vesicles, and linings of the eyes. This increases the risk of infections and can cause infertility in women and sterility in men.

hyperkeratosis A clinical condition resulting from the overproduction of the skin protein known as keratin. Overproduction of keratin plugs skin follicles, thickens the skin surface, and causes skin to become bumpy and scaly. Vitamin A deficiency is related to hyperkeratosis.

What are the symptoms of vitamin A toxicity?

Toxicity of vitamin A is rare except in cases of megadoses of vitamin A supplements. Children may be at greater risk of toxicity. Vitamin A toxicity produces a wide range of symptoms, including skin conditions, vomiting, fatigue, blurred vision, and liver damage. Vitamin A toxicity can be fatal. The tolerable UL for vitamin A is 3000 micrograms per day of retinol.

Which foods are rich in vitamin A?

Animal food sources of retinoids are beef and chicken liver (see Figure 6.12), and milk. Fruits and vegetables that contain high amounts of the carotenoids provide substantial vitamin A in the diet when converted to retinol equivalents. Vitamin A–fortified dairy products provide additional sources of vitamin A in the United States.

What is a suggestion for a vitamin A–rich meal or snack?

Lunch: Mix 1/2 can of salmon (oil-packed), 1 tsp light salad dressing, and chopped onion, celery, and tomato; serve on 2 slices of whole grain bread with 1/2 cup fresh fruit and 1 cup low-fat milk
Vitamin A content: 365 micrograms (RAE)

VITAMIN A

Daily Value = 5000 IU
RDA = 900 μg (males), 700 μg (females)

	Food	Amount	Vitamin A
Exceptionally good sources	Beef liver, cooked	85 g (3 oz)	22,175 IU
	Sweet potato	110 g (1 small)	21,140 IU
	Carrots, cooked	85 g (~1/2 cup)	19,152 IU
	Chicken liver, cooked	85 g (3 oz)	12,221 IU
High: 20% DV or more	Spinach, cooked	85 g (~1/2 cup)	8,909 IU
	Spinach, raw	85 g (~3 cups)	7,970 IU
	Collards, cooked	85 g (~1/2 cup)	6,897 IU
	Romaine lettuce, raw	85 g (~1 1/2 cups)	4,936 IU
	Cantaloupe, fresh	140 g (1/4 med. melon)	4,735 IU
	Peppers, red, cooked	85 g (~1/2 cup)	4,265 IU
	Broccoli, cooked	85 g (~1/2 cup)	1,716 IU
	Watermelon, fresh	280 g (1/16 melon)	1,593 IU
	Oatmeal, instant, fortified, cooked	1 cup	1,252 IU
	Tomato juice, canned	240 ml (1 cup)	1,094 IU
	Mango, fresh	140 g (~1 cup)	1,071 IU
Good: 10–19% DV	Apricot, dried	40 g (~3 Tbsp)	856 IU
	Wheat bran flakes cereal	30 g (3/4 cup)	788 IU
	Prunes, dried	40 g (~5 prunes)	705 IU
	Black-eyed peas, cooked	90 g (~1/2 cup)	712 IU
	Green beans, cooked	85 g (~3/4 cup)	595 IU
	Corn flakes cereal	30 g (1 cup)	537 IU
	All-bran cereal	30 g (1/2 cup)	524 IU
	Milk, 1%, 2%, nonfat	240 ml (1 cup)	500 IU

Figure 6.12 Food sources of vitamin A. Vitamin A is found as retinol in animal foods and as beta-carotene and other carotenoids in plant foods. Units are IU to be consistent with DV definitions.
Source: Data from U.S. Department of Agriculture, Agricultural Research Service, 2012. USDA National Nutrient Database for Standard Reference, Release 25. Nutrient Data Laboratory home page. Available at: http://www.ars.usda.gov/ba/bhnrc/ndl.

Do athletes need vitamin A supplements?

Helping athletes meet the RDA for vitamin A from food sources appears to be the most prudent current recommendation. Research on supplementing vitamin A in amounts greater than the RDA to improve sport performance has not shown any ergogenic value. Therefore, encouraging athletes to obtain vitamin A from food sources rather than supplements to avoid toxicity is recommended.

Why are the carotenoids important for athletes?

The carotenoids are a group of naturally occurring compounds found in plants. They are colorful compounds that give plants and their fruit the deep colors of orange, red, and yellow. Dark green vegetables also contain carotenoids, but the chlorophyll in these plants gives them their green color and masks the carotenoid colors. Carotenoids are not vitamins; however, because some of them can be converted to vitamin A, discussion of these compounds has been included in this chapter. There are approximately 600 different carotenoids identified in plants. The major carotenoids include alpha- and beta-carotene, lycopene, lutein, zeaxanthin, and cryptoxanthin. As discussed previously, some carotenoids are precursors to vitamin A. These provitamin A carotenoids are beta-carotene, alpha-carotene, and beta-cryptoxanthin. Because they have no vitamin A activity in the body, lycopene, lutein, and zeaxanthin are called non-provitamin A carotenoids.

Carotenoids as precursors to vitamin A play a role in vitamin A functions. However, they also have additional functions in the body that are exclusive to carotenoids. They have roles as antioxidants, bolster immune function, aid in cancer prevention, and enhance vision. Beta-carotene and other carotenoids are powerful antioxidants that interfere with free radical activity (refer to the "What are free radicals?" section later in this chapter). The carotenoids work primarily to keep free radical production from becoming uncontainable and thus prevent any negative health effects. As an example, two carotenoids, lutein and zeaxanthin, are found in the macula of the eye. The function of the macula is to provide detailed and sharp vision. It is theorized that lutein and zeaxanthin help filter the harmful light entering the macula and scavenge free radicals in the retinal tissues. This theory is reinforced by recent epidemiological studies that have suggested that increased intake of lutein lowers the risk for age-related macular degeneration.

free radicals Highly reactive molecules, usually containing oxygen, that have unpaired electrons in their outer shell. Because of their highly reactive nature, free radicals have been implicated as culprits in diseases ranging from cancer to cardiovascular disease.

Fortifying Your Nutrition Knowledge

Tips for Increasing Carotenoid Intake

Athletes can increase their carotenoid intake by:

- Eating 5 to 9 servings per day of fruits and vegetables.
- Choosing more colorful vegetables and fruits, including reds, yellows, blues, and purples.
- Including at least one vegetable or fruit in each meal and a serving of fruit or vegetables as a snack.
- Drinking 6–8 oz of 100% fruit juice, such as grape, orange, grapefruit, or cranberry, with breakfast.

What is the RDA/AI for carotenoids?

There are no established RDA/AIs for the carotenoids. However, carotenoid consumption was taken into consideration when developing the RAE used to establish the RDA and UL for vitamin A. A large body of observational epidemiological evidence suggests that higher blood concentrations of beta-carotene and other carotenoids obtained from foods are associated with lower risk of several chronic diseases.[28] The evidence appears to be consistent in the studies but cannot be used to establish specific RDAs for carotenoids because it is unclear whether the carotenoids alone or other substances in the foods consumed produced the desired effects. Although no DRIs are established for carotenoids, the Food and Nutrition Board recommends eating foods rich in carotenoids and avoiding supplementation.[28]

gaining the performance edge

Carotenoids are a unique category of plant-based substances that can positively affect overall health. Some functions, including improved immune function and antioxidant activity, may also be beneficial to athletic performance. Although no DRI has been set for these compounds, a diet rich in dark, colorful fruits and vegetables has been found to be advantageous to health and well-being.

Which foods are rich in carotenoids?

Most colorful fruits and vegetables contain carotenoids. The best sources include deep red, yellow, and orange fruits and vegetables. Tomatoes and tomato products, red peppers, leafy greens, apricots, watermelon, cantaloupe, pumpkin, squash, sweet potatoes, carrots, and oranges are all excellent sources of carotenoids.

Why is vitamin D important for athletes?

Vitamin D is a unique fat-soluble vitamin because, in general, all of the body's needs for it can be met by synthesis within the body. It is sometimes called the "sunshine vitamin" because the ultraviolet rays of the sun hitting the skin initiate vitamin D synthesis in the body. However, vitamin D may not be produced in high enough quantities in the following instances: in geographic locations where sunlight is marginal; during seasons when sunshine is insufficient; in instances when people are told to stay out of the sun; or in instances when individuals are physically unable or infirmed and cannot go outside. It is in these cases that vitamin D, from food or supplemental sources, is essential and, as a result, is considered a vitamin.

The primary role of vitamin D in the body is to control calcium levels in the blood, which, in turn, affects bone growth and development. However, vitamin D itself is not the active compound that affects the body's calcium levels. It first must be converted through a series of reactions in the liver and then the kidneys to **calcitriol** (see Figure 6.13). Cholecalciferol (from animal foods and sunlight conversion) and ergocalciferol (from plant foods) can both be converted to calcitriol. Sunlight exposure initiates the process by converting 7-dehydrocholesterol in the skin to cholecalciferol. This converted cholecalciferol is carried to the liver, where it and dietary cholecalciferol and ergocalciferol are converted to calcidiol. Calcidiol is then transported to the kidneys, where calcitriol is formed. Calcitriol is the active form of vitamin D in the body. Because calcitriol is produced in one area of the body (the kidneys), carried in the blood, and then exerts effects on tissues in other areas of the body (e.g., bone), it can also be considered a hormone.

calcitriol The active form of vitamin D in the body. It plays a vital role in calcium regulation and bone growth.

The total extent to which vitamin D acts as a hormone is not fully understood; however, research is providing compelling evidence that its importance to the body is more widespread than previously thought. Vitamin D is not only crucial for bone health, as previously noted, but also important for immune function, control of inflammation, and even muscle function.[31] In fact, vitamin D deficiency has been associated with increased risk for several chronic and autoimmune diseases, such as hypertension, cardiovascular disease, rheumatoid arthritis, depression, and certain cancers.[31] The growing evidence regarding the importance of vitamin D has caused some nutrition professionals and researchers to question the current intake recommendations discussed below as being too low.

What is the RDA/AI for vitamin D?

The RDA for vitamin D assumes that no vitamin D is available from synthesis from exposure to sunlight. For men and women aged 19 to 70 years, the RDA is 600 IU per day.[32] For men and women older than 70, the RDA is 800 IU per day. As people age, they have less ability to synthesize vitamin D from sun exposure; therefore, as age increases, the RDA also increases. Similar to vitamin A, International Units (IU) are used to express vitamin D recommendations. The IU is presented on food labels and is used as the unit level for %DV.

What are the complications of vitamin D deficiency?

Because of the profound effect vitamin D has on absorption of dietary calcium, vitamin D deficiency can have devastating effects on bone growth and development in children. In children, vitamin D deficiency leads to rickets, which results in poorly formed, weak, and soft bones. In adults, deficiency of vitamin D increases the risk for osteoporosis. Fortunately, the fortification of milk with vitamin D has virtually wiped out deficiency problems in children in the United States. Osteoporosis, however, is an increasing concern for older adults. Adequate vitamin D intake in food or supplement form is an essential part of prevention and treatment of osteoporosis in the aging population. In elderly individuals who are house-bound and do not receive regular exposure to sunlight, adequate dietary vitamin D intake must be ensured.

In athletes, vitamin D deficiency may manifest itself in a variety of ways. Muscle weakness, muscle pain, chronic injury, frequent illness, changes in bowel function, and bone pain can all be signs of a vitamin D deficiency. Unfortunately, these symptoms are also indicative of other health conditions and as a result, screening for vitamin D deficiency via blood

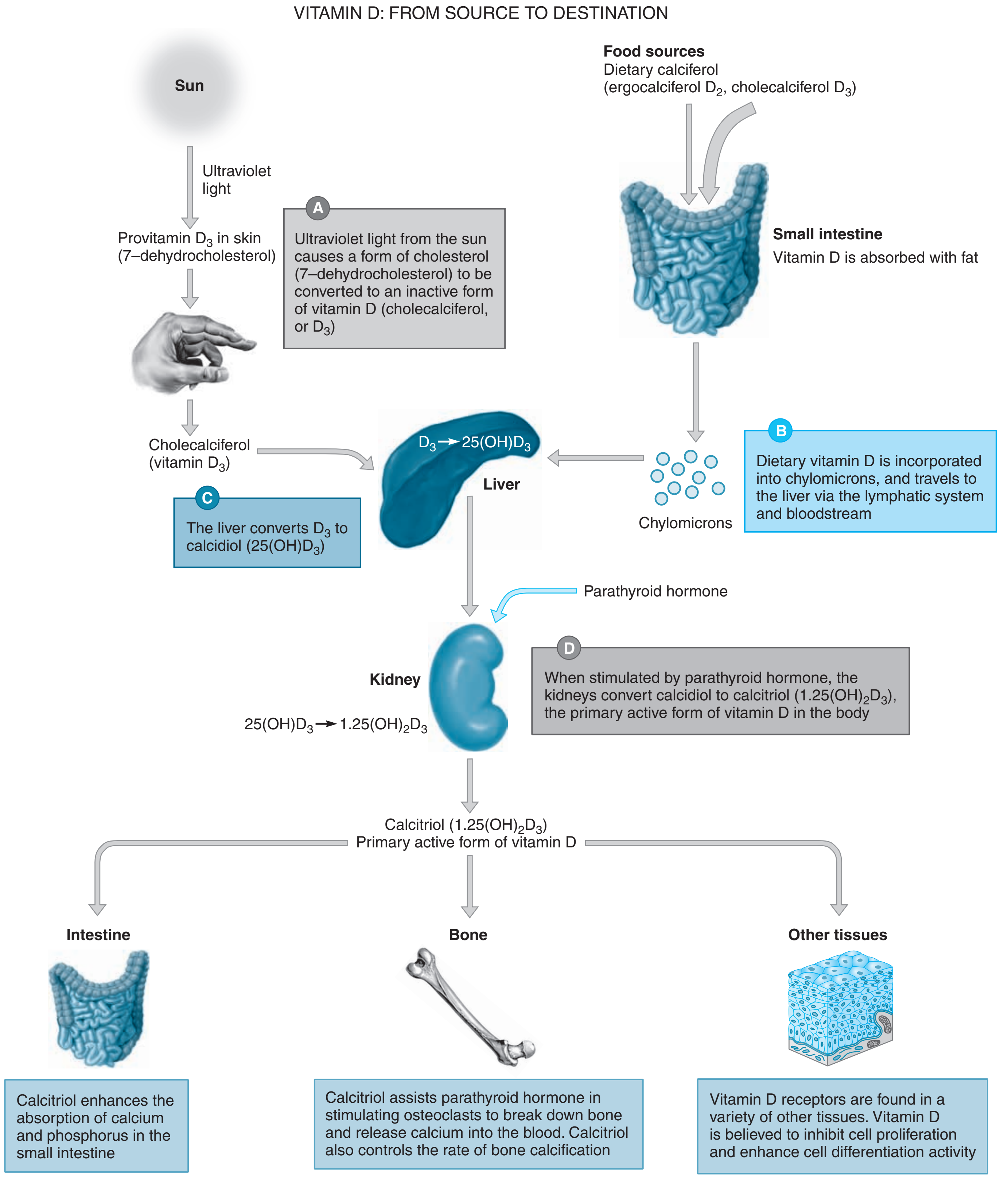


Figure 6.13 Vitamin D: from source to destination. Vitamin D is unique because, given sufficient sunlight, the body can synthesize all it needs. Both dietary and endogenous vitamin D must be activated by reactions in the kidneys and liver. Active vitamin D (calcitriol) is important for calcium balance and bone health, and may have a role in cell differentiation.

TABLE 6.2 Serum Vitamin D [25(OH)D] Concentrations and Status

Serum Concentration (nmol/L)*	Serum Concentration (ng/mL)*	Status
<30	<12	Associated with vitamin D deficiency, leading to rickets in infants and children and osteomalacia in adults.
30–50	12–20	Generally considered inadequate for bone and overall health.
≥50	≥20	Generally considered adequate for bone and overall health.
>125	>50	Potential adverse effects due to toxicity, particularly >150 nmol/L (>60 ng/mL).

*Serum concentration of vitamin D are reported both in nanomoles per liter (nmol/L) and nanograms per milliliter (ng/mL).

Source: Reproduced from National Institutes of Health, Office of Dietary Supplements, 2011. *Dietary Supplement Fact Sheet: Vitamin D.* Available at: http://ods.od.nih.gov/factsheets/VitaminD-HealthProfessional/. Accessed November 14, 2012.

testing is recommended for athletes. See **Table 6.2** for reference ranges of vitamin D screening.

What are the symptoms of vitamin D toxicity?
Because it is stored in the body, toxicity of vitamin D can occur. Overexposure to the sun or dietary intake of vitamin D from food sources is unlikely to cause toxicity, but supplementation in high doses can cause problems. The UL for vitamin D for adults over age 19 is 4000 IU. Overdosing with vitamin D causes hypercalcemia, or high blood calcium. Hypercalcemia causes a depressed function of the nervous system, muscular weakness, heart arrhythmias, and calcium deposits in the kidneys (i.e., kidney stones), blood vessels, and other soft tissues.

hypercalcemia A clinical condition in which blood calcium levels are above normal.

Which foods are rich in vitamin D?
Food sources of vitamin D come in natural and fortified forms (see Figure 6.14). Fortified forms are included in milk, cereals, orange juice, and some margarines. Natural sources include fish oils, salmon, sardines, herring, egg yolks, and liver. Plants are poor sources of vitamin D; therefore, strict vegetarians need to rely on the endogenous production of vitamin D from sun exposure or the consumption of fortified foods and the use of supplements.

What is a suggestion for a vitamin D–rich meal or snack?
Bedtime snack: 12 oz skim milk and 2 oatmeal raisin cookies
Vitamin D content: 158 IU

Do athletes need vitamin D supplements?
Vitamin D fortification in milk and other foods and the fact that it is manufactured in the body would seem to suggest that most individuals, athletes included, maintain adequate amounts of vitamin D. However, few studies have reported on vitamin D status in athletes. A review of the literature on vitamin D and athletes revealed that many border on the line between inadequate and adequate intake of vitamin D as determined by blood serum analysis.[31] This is why many nutrition professionals are now suggesting that athletes have their blood serum levels for vitamin D tested. Athletes who train

VITAMIN D

Daily Value = 400 IU
RDA = 600 IU age 19–70 (males/females)
800 IU age 70+ (males/females)

	Exceptionally good source		
	Cod liver oil	1 Tbsp	1360 IU
High: 20% DV or more	Salmon, canned, solids + bones	55 g (2 oz)	343 IU
	Sardines, canned, solids + bones	55 g (2 oz)	150 IU
	Milk, nonfat	240 mL (1 cup)	105 IU
	Milk, 1%, 2% milkfat	240 mL (1 cup)	102 IU
	Fortified orange juice	240 mL (1 cup)	100 IU
	Milk, whole, 3.25% milkfat	240 mL (1 cup)	98 IU
Good: 10–19% DV	Fortified, ready-to-eat cereals	30 g	40–50 IU
	Beef liver	85 g	40 IU
	Egg yolk	1 large	37 IU

Figure 6.14 Food sources of vitamin D. Only a few foods are naturally good sources of vitamin D. Therefore, fortified foods such as milk and some cereals are important, especially for people with limited exposure to the sun. Units are IU to be consistent with DV definitions.
Source: Data from U.S. Department of Agriculture, Agricultural Research Service, 2012. USDA National Nutrient Database for Standard Reference, Release 25. Nutrient Data Laboratory home page. Available at: http://www.ars.usda.gov/ba/bhnrc/ndl.

extensively indoors or who consume lower or inadequate amounts of calories or whose food choices do not include vitamin D–rich sources daily may need and benefit from supplementation. In addition to supplementation, the following strategies will help contribute to vitamin D levels in the body:

- Obtain exposure to the sun for 15 minutes every day. Even exposure on the face and hands is enough to synthesize adequate vitamin D. However, athletes should protect their skin from too much sun exposure and sunburn.
- Drink milk with meals or as a snack.
- Consume fortified cereals with milk for breakfast.
- Try canned or fresh salmon as an alternative to tuna.

Why is vitamin E important for athletes?

Vitamin E is actually a group of compounds that include the tocopherols and the tocotrienols. Both tocopherols and tocotrienols contain four compounds each: the alpha, beta, gamma, and delta configurations. The tocopherols are more widely distributed in nature than tocotrienols and contribute most of the dietary sources of vitamin E. Although all of these compounds can be absorbed in the body, only alpha-tocopherol is considered to have vitamin E activity in the body.[28] It is the alpha-tocopherol configuration of vitamin E that is used to determine the RDA values.

The primary role of vitamin E in the body is as an antioxidant. Antioxidants protect the body from highly reactive molecules known as free radicals (refer to the "What are free radicals?" section later in this chapter). Free radicals are molecules that have unpaired electrons, which give the molecules an electrical charge, thus making them unstable and highly reactive. If not neutralized, free radicals will react with molecules in the body, potentially changing these molecules' structure and/or function. The end result can be an increased risk for damage to tissues such as the skin and other connective tissues. The role vitamin E plays in protecting the skin and its underlying connective tissues is one reason why vitamin E has been advertised as the "anti-aging" vitamin.

Vitamin E not only protects the skin and connective tissues, but also helps to protect the cell membranes and genetic material of virtually all tissues of the body. Free radicals are highly reactive with fatty acids. Because cell membranes are made up of phospholipids (i.e., they contain fats), cell membranes can be attacked by free radicals. Vitamin E protects cell membranes by directly reacting with free radicals, thus preventing them from reacting with the fatty acids in the cell membranes. Free radicals can also react with the genes inside the nuclei of cells, resulting in genetic mutations that could cause aberrant cell growth and/or cancer; vitamin E can help prevent these genetic alterations. Dietary intake of appropriate amounts of vitamin E helps to provide adequate levels of this very important antioxidant vitamin.

What is the RDA/AI for vitamin E?

The RDA for vitamin E is 15 milligrams of alpha-tocopherol for men and women.[28] As with vitamin A, the discontinued International Units (IU) are still found on supplement labels. To convert IU to milligrams of vitamin E, use the following equations:

1 IU = 0.67 mg of the natural form of alpha-tocopherol
1 IU = 0.45 mg of the synthetic form of alpha-tocopherol

To meet the RDA recommendations of 15 milligrams, the IU equivalent is 23 IU for the natural form and 34 IU for the synthetic form.

What are the complications of vitamin E deficiency?

Overt deficiency of vitamin E is rare because it appears dietary intake is adequate in the general population. Individuals who choose extremely low-fat or fat-free diets could develop vitamin E deficiency over time. Conditions resulting in malabsorption or maldigestion of lipids, such as cystic fibrosis, celiac disease, or hepatic or biliary diseases, may result in poor absorption of vitamin E and thus compromise vitamin E status. Common signs of vitamin E deficiency take time to develop and are related to the breakdown of cell membranes. Muscle weakness and loss of motor coordination can result because of cell membrane damage to muscle and nerve tissue, respectively. In addition, the breakdown of cell membranes of red blood cells results in hemolytic anemia, causing lack of energy and decreased physical functioning.

What are the symptoms of vitamin E toxicity?

Vitamin E is less likely than other fat-soluble vitamins, such as A and D, to become toxic to the body. However, high doses of vitamin E resulting from supplementation can affect vitamin K's blood-clotting functions, leading to excessive bleeding and easy bruising. The UL for adults is 1000 milligrams of alpha-tocopherol.

VITAMIN E

Daily Value = 30 IU
RDA = 15 mg (males/females)

	Food	Serving	Amount
Exceptionally good sources			
	Wheat bran flakes cereal	30 g (~3/4 cup)	41.7 IU
	Wheat germ oil	1 Tbsp	30.5 IU
	Total cereal	30 g (~3/4 cup)	30.2 IU
	Product 19 cereal	30 g (~1 cup)	30.2 IU
High: 20% DV or more	Sunflower seeds	30 g (~1 oz)	15.5 IU
	Almonds	30 g (~1 oz)	11.6 IU
	Cottonseed oil	1 Tbsp	7.2 IU
	Safflower oil	1 Tbsp	7.0 IU
	Special K cereal	30 g (~1 cup)	7.0 IU
	Hazelnuts	30 g (~1 oz)	6.8 IU
	Tomato paste, canned	130 g (~1/2 cup)	6.0 IU
Good: 10–19% DV	Corn oil	1 Tbsp	4.2 IU
	Peanuts	30 g (~1 oz)	3.8 IU
	Spinach, frozen, cooked	85 g (~1/2 cup)	3.0 IU

Figure 6.15 Food sources of vitamin E. Nuts and seeds, vegetable oil, and products made from vegetable oil, such as margarine, are among the best sources of vitamin E. Units are IU to be consistent with DV definitions. The DV for vitamin E is higher than the current RDA of 15 milligrams (23 IU) for males and females age 19 and older. Note: USDA tables list vitamin E in mg alpha-tocopherol equivalents. Conversion to IU was done using 1 mg ATE = 1.5 IU.

Source: Data from U.S. Department of Agriculture, Agricultural Research Service, 2012. USDA National Nutrient Database for Standard Reference, Release 25. Nutrient Data Laboratory home page. Available at: http://www.ars.usda.gov/ba/bhnrc/ndl.

Which foods are rich in vitamin E?

Common food sources of vitamin E include both plant and animal products (see Figure 6.15). Plant oils such as corn, safflower, cottonseed, sunflower, soy, and palm oils are good sources of vitamin E. Products made from these oils, such as margarine, shortening, mayonnaise, and salad dressings, also contain vitamin E. Fortified cereals can be a good source of this vitamin; however, not all cereals are fortified with vitamin E. Animal sources such as meat, poultry, and fish are at best moderate contributors to dietary vitamin E.

What is a suggestion for a vitamin E–rich meal or snack?

Nutty black bean salad: Mix together 1 cup black beans; 1 tbsp sunflower seeds; ¼ cup each chopped tomato, corn, and green pepper; 1 tbsp corn oil; and 1 tbsp balsamic vinegar. Serve with whole grain bread and fruit juice.

Total vitamin E content = 27 IU or 18 milligrams alpha-tocopherol

Do athletes need vitamin E supplements?

Much research has been conducted on vitamin E supplementation in hopes of finding an ergogenic effect in athletes. This research has focused on vitamin E's antioxidant effects during exercise. The impact of antioxidants is discussed later in the chapter.

Why is vitamin K important for athletes?

Vitamin K belongs to the quinone family of compounds and is probably the least known of the fat-soluble vitamins. The primary role of vitamin K in the body is in blood clotting. When a laceration or an abrasion occurs, a series of activation reactions involving clotting factors is required to stop the bleeding. Vitamin K is essential in many of the steps of the clotting process. Without vitamin K, even a single cut could be life-threatening from the potential blood loss. Vitamin K is also important to bone health. It assists in the mineralization of bone with calcium, thus keeping bones dense and strong.

What is the RDA/AI for vitamin K?

Because of the lack of data regarding average requirements, no RDA has been established for vitamin K. As a result, AI is used to represent intake levels. The AI for vitamin K for men older than 19 years of age is 120 micrograms; for women older than 19 years of age, the AI is 90 micrograms daily.[30]

What are the complications of vitamin K deficiency?

A deficiency of vitamin K impairs blood clotting and can lead to substantial hemorrhaging. Thus, vitamin K is important to athletes, who are much more likely than the general population to receive cuts, tears, and abrasions as a result of their sport participation. The body needs only small amounts of vitamin K, and it can produce some of the daily requirement through the action of intestinal bacteria. The intestinal bacteria can produce approximately 10–15% of the vitamin K in the body.[33] The vitamin K produced by the body along with dietary vitamin K is absorbed with fat in the intestines, packaged into chylomicrons, and transported via the lymphatic system to the liver. Individuals more prone to vitamin K deficiency include those with fat malabsorptive conditions such as celiac disease, Crohn's disease, and cystic fibrosis and those taking long-term antibiotics that may reduce the intestinal bacteria. Newborn babies may be at risk for vitamin K deficiency because they lack the intestinal bacteria at birth that produce vitamin K. Breast milk also contains very little vitamin K. Most newborn babies are given a vitamin K injection at birth, and within several weeks the intestinal bacteria will provide adequate vitamin

K for the newborn's needs. Individuals using antibiotics for a prolonged period may be at higher risk of deficiency because antibiotics may kill the naturally occurring bacteria in the gut that produce vitamin K.

What are the symptoms of vitamin K toxicity?
Vitamin K is excreted from the body much more readily than the other fat-soluble vitamins, making vitamin K toxicity rare. A UL has not been established because few adverse effects have been reported for individuals consuming high amounts of vitamin K.

Which foods are rich in vitamin K?
Like vitamin D, vitamin K can be made endogenously. However, the body cannot make enough vitamin K to meet all of its needs. The best dietary sources of vitamin K are green leafy vegetables such as spinach and broccoli. Other foods such as milk, eggs, wheat cereals, and some fruits and vegetables contain small amounts of vitamin K (see Figure 6.16).

What is a suggestion for a vitamin K–rich meal or snack?
Green vegetable salad: 1 cup spinach, $\frac{1}{2}$ cup chopped broccoli, 1 chopped hard-boiled egg, 4 diced scallions, and $\frac{1}{4}$ cup carrot shreds served with 1 tbsp light ranch dressing
Total vitamin K content = 170 micrograms

Do athletes need vitamin K supplements?
There are no known studies that support an increased need for vitamin K in athletes. Supplementation may be indicated for individuals with risks for deficiency or who present with deficiency symptoms. Supplementation should be provided with physician guidance and supervision, and often requires a prescription. Athletes who are injured and require surgery should inform their physician prior to surgery about any vitamin supplements they use regularly. Most surgeons require their patients to stop taking multivitamins prior to surgery because some vitamins can increase clotting times, increasing the risk of bleeding during surgery.

gaining the performance edge

Fat-soluble vitamins include vitamins A, D, E, and K. Each vitamin has its own function in the body, DRI, complications of deficiency, symptoms of toxicity, unique food sources, and requirements for supplementation. All fat-soluble vitamins are critical to health, and therefore a variety of food sources should be consumed daily to meet the needs of each nutrient.

VITAMIN K

Daily Value = 80 µg
AI = 120 µg (males), 90 µg (females)

	Food	Amount	Vitamin K
Exceptionally good sources	Spinach, raw	85 g (~3 cups)	410 µg
	Turnip greens, raw	85 g (~3 cups)	213 µg
	Cauliflower, raw	85 g (~$\frac{3}{4}$ cup)	136 µg
	Broccoli, cooked	85 g (~$\frac{1}{2}$ cup)	120 µg
	Romaine lettuce, raw	85 g (~$1\frac{1}{2}$ cups)	87 µg
High: 20% DV or more	Chicken liver, cooked	85 g (3 oz)	68 µg
	Cabbage, raw	85 g (~$1\frac{1}{4}$ cups)	51 µg
	Asparagus, cooked	85 g (~$\frac{1}{2}$ cup)	43 µg
	Okra, cooked	85 g (~$\frac{1}{2}$ cup)	32 µg
	Prunes, dried	120 g (~$\frac{1}{2}$ cup)	31 µg
	Soybean oil	1 Tbsp.	27 µg
	Blackberries, raw	140 g (~1 cup)	27 µg
	Blueberries, raw	140 g (~$\frac{3}{4}$ cup)	27 µg
Good: 10–19% DV	Green beans, cooked	85 g (~$\frac{2}{3}$ cup)	14 µg
	Artichokes, cooked	85 g (~$\frac{1}{2}$ cup)	13 µg
	Tomato, green, raw	85 g (1 small)	8.6 µg

Figure 6.16 Food sources of vitamin K. The best sources of vitamin K are vegetables, especially those in the cabbage family. Liver, eggs, and milk are good sources as well. Note: The DV for vitamin K is lower than the current AI of 120 micrograms and 90 micrograms for males and females, respectively, age 19 and older.
Source: Data from U.S. Department of Agriculture, Agricultural Research Service, 2012. USDA National Nutrient Database for Standard Reference, Release 25. Nutrient Data Laboratory home page. Available at: http://www.ars.usda.gov/ba/bhnrc/ndl.

Which vitamins or compounds have antioxidant properties?

Two of the fat-soluble vitamins, A (including the carotenoids) and E, and the water-soluble vitamin C all have powerful antioxidant properties in the body. As mentioned earlier, antioxidants protect tissues of the body from highly reactive molecules known as free radicals. The following sections discuss free radicals, their association with exercise, and the role that vitamins A, E, and C play in combating them.

What are free radicals?

To understand the antioxidant functions of vitamins and other compounds in the body, it is important to first have a basic knowledge of free radicals, where they come from, and how they are eliminated. Free radicals are highly reactive molecules, usually containing oxygen, that possess unpaired electrons in their structure (see Figure 6.17). The unpaired electrons give free radicals an ionic charge, which makes them

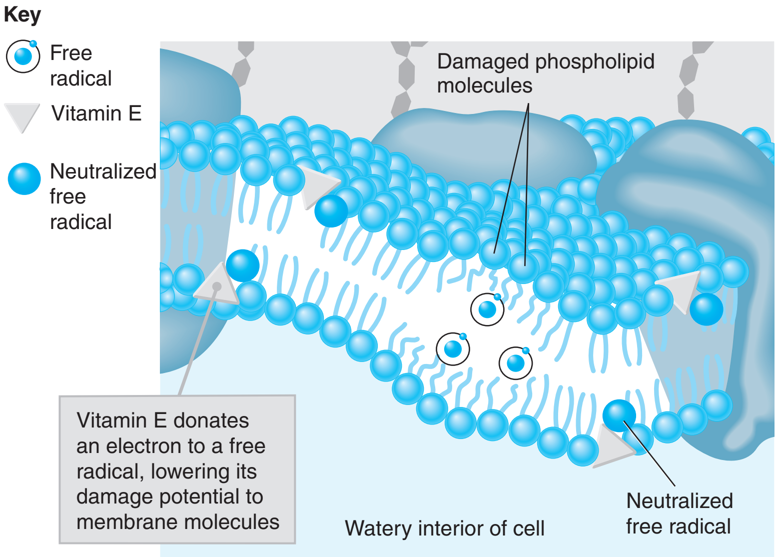


Figure 6.17 Free radical damage. Vitamin E helps prevent free radical damage to polyunsaturated fatty acids in cell membranes.

reactive with other charged molecules in the body. Free radicals basically cause molecules to give up electrons in a process known as oxidation so that they can match any unpaired electrons and become more stable. Undesirable free radical oxidation may damage DNA, lipids, proteins, and other molecules and thus may be involved in the development of cancer, cardiovascular disease, and possibly nerve degenerative diseases.

Free radicals are produced in the body as by-products of normal cellular metabolism or can be taken into the body from outside sources. Outside sources of free radicals include the breathing of polluted air, such as when runners exercise in congested traffic. Within the body, free radicals produced in the mitochondria of cells as hydrogen ions are transferred to oxygen to form water (H_2O) in the electron transport chain. However, occasionally oxygen is not paired with hydrogen ions to form water and instead forms ionically charged free radical molecules, such as superoxide (O_2), hydroxyl (OH), and peroxyl (H_2O_2) radicals. These oxygen-containing molecules are collectively known as **reactive oxidative species (ROS)**. As noted earlier, if these reactive molecules go unchecked in the body, they can be very destructive.

reactive oxidative species (ROS) Free radical molecules that contain oxygen in their molecular formula and that are formed during aerobic metabolism. Commonly occurring reactive oxidative species in the human include superoxidases, hydroxyl radicals, and peroxyl radicals.

lipid peroxidation A chemical reaction in which unstable, highly reactive lipid molecules containing excess oxygen are formed.

Fortunately, the body has access to compounds that help neutralize the oxidative stresses imposed by free radicals, thereby protecting the body from damage. These protective compounds are collectively known as antioxidants. The body produces a variety of antioxidant enzymes capable of catalyzing reactions that neutralize free radicals. In addition, healthy dietary practices supply the body with antioxidant vitamins such as vitamins A (including the carotenoids), E, and C. These nonenzymatic antioxidants either directly interact with free radicals (see Figure 6.18) or work as coenzymes. In summary, the body's antioxidants, whether enzymatic or nonenzymatic, are crucial to helping the body protect itself from free radicals.

An example of the damage that can be caused by free radicals involves a process known as **lipid peroxidation**. During lipid peroxidation the double bond of an unsaturated fatty acid is broken, yielding intermediate compounds that can react with oxygen to form peroxyl free radicals. A peroxyl free radical has one unpaired electron, making it highly reactive with other fatty molecules within the cell membrane. To help decrease the cell membrane damage, vitamin

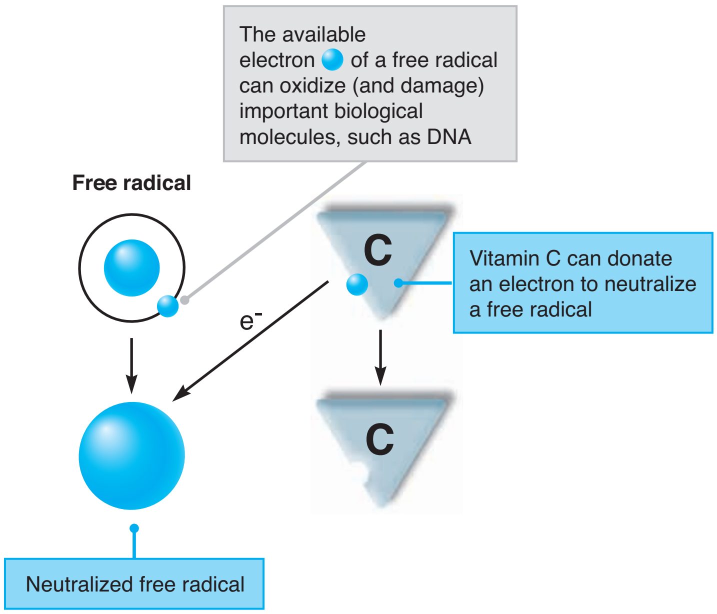


Figure 6.18 Vitamin C minimizes free radical damage by donating an electron to the free radical.

E responds to the free radical by donating an electron, thus preventing it from reacting with other fatty acids in the cell membrane and causing further damage (see Figure 6.17). At this point, vitamin E needs an electron and is essentially a free radical itself, though not a very reactive one. Vitamin E can get an electron from another antioxidant, such as vitamin C. Vitamin C, in turn, regains its lost electron from glutathione. To stop this cascading process, the enzyme glutathione reductase restores glutathione to its original form with help from selenium, a mineral. Antioxidant vitamins are commonly referred to independently and do have distinct and independent functions within the body; however, they also work together to keep the body functioning and prevent cellular damage.

What is the relationship between free radicals and exercise?

Free radical production has been shown to increase during exercise, particularly sustained aerobic exercise performed at high intensity.[34–36] The reason for the increase in free radical production with increasing levels of exercise is not well understood but is believed to be related to the increased presence and utilization of oxygen by the mitochondria within the muscle cells to make ATP. As noted earlier, cells continuously produce free radicals as a part of normal metabolism.[37] The free radicals that are produced are usually neutralized by an elaborate antioxidant defense system of enzymatic and nonenzymatic antioxidants. Exercise increases aerobic metabolism and thus may create an imbalance between free radical production and their neutralization by antioxidants.[36,37] Interestingly, it appears that the body's own natural antioxidant defense system is adaptable and up-regulates its response to extended training.[38] This appears to strengthen the body's antioxidant defense mechanism and serves to protect muscle and other tissues from damage during future exercise bouts.

Do athletes need antioxidant supplements?

Antioxidants are beneficial compounds in the human body.[34,39] Without them, oxidation would not be controlled and many processes would suffer. Supplementation with antioxidant vitamins and minerals would appear to make sense for individuals interested in the potential health benefits of antioxidants. Finding ways to prevent the devastation of chronic diseases such as heart disease, cancer, and other illnesses is important for athletes as well as the general population. Although the use of antioxidants is promising, there are still no governing bodies that recommend regular intake of antioxidants at levels higher than the RDA/AIs.

However, there is valid reasoning for the interest in antioxidant supplementation use by athletes.[3,38] If, as noted earlier, exercise training can bolster the body's natural free radical defense mechanism, then why wouldn't nonenzymatic antioxidant supplementation also increase the defense against free radicals? Unfortunately, research into the effects of taking nonenzymatic antioxidant supplements (i.e., vitamins A, C, and E) on free radical levels during exercise is presently unclear. The problem is that free radical levels are difficult to measure directly because they are so highly reactive. Therefore, scientists must rely on markers that might indicate the presence of free radicals, such as cellular damage or other molecules that result because of reactions with free radicals. However, using indirect indicators of free radical activity is prone to error and explains the equivocal research results to date. In addition, some argue that the real issue is the body's 24-hour ability to neutralize free radicals, and that the relatively brief intervals of exercise and their associated increased production of free radicals are just a minor, short-lasting spike in the 24-hour battle against free radicals. The bottom line is that so little is known about the effects of antioxidant supplementation on exercise that making recommendations to well-nourished athletes regarding antioxidant supplementation currently is neither necessary nor advisable.[40] For now, the best nutrition advice is to incorporate more antioxidant-containing foods into the daily diet to ensure adequate intake of a variety of antioxidants and other nutrients.

gaining the performance edge

Antioxidants are beneficial compounds in the human body that are particularly helpful in maintaining overall health and preventing chronic disease. The ergogenic effects of antioxidants have not yet been clearly elucidated but continue to be a focus of exercise science research. Current recommendations call for intakes at the established RDA/AIs, with a strong focus on whole food sources.

Food for Thought 6.2

Importance of Vitamin Intake for Athletes: Fat-Soluble Vitamins and Antioxidants

Review the recommendations, food sources, and significance of fat-soluble vitamins and antioxidants for athletes.

What are phytochemicals?

Although phytochemicals are not nutrients, they have important health functions. The term *phytochemicals* comes from the Greek word *phyto*, meaning "plant"; they are so named because they are chemical substances found in plants. In their 1991 publication, Steinmetz and Potter[41] identified more than a dozen classes of biologically active plant chemicals known as phytochemicals. It is estimated that there are thousands of these plant chemicals that may or may not significantly affect the human body. Approximately 50 phytochemicals are commonly consumed in the American diet. Research on the many benefits of phytochemicals to human health varies for different classes and specific compounds. Evidence clearly supports consumption of a diet rich in fruits, vegetables, and whole grains in helping individuals stay healthy and reduce the risk of cardiovascular disease and cancer.[42,43] However, further research is needed to determine what role specific phytochemicals play in reducing these chronic diseases. The effect of phytochemicals on exercise and sport performance is not well researched.

Dietitians and other health professionals who educate the public about healthful eating must be aware of the different types of phytochemicals in foods.[44,45] Consumers are savvy about the latest research and want more information about how they can benefit by eating more nutrient-dense foods. In a study of the effects of one educational session on functional food consumption, 79% of participants expressed intent to eat more tomatoes/tomato products, and 75–77% indicated intent to consume purple grape juice, oats, and broccoli.[46,47] In addition, many consumers may not be aware of the health benefits of consuming more plant-based foods. Fruits, vegetables, and grain products contain many more components than just the vitamins and minerals found in a multivitamin supplement.

This section briefly describes three classifications of phytochemicals that have fairly solid research evidence suggesting a health-protective role. These classifications are the phenolic compounds, organosulfides, and one of the carotenoids, lycopene. More research is required to fully understand phytochemicals' roles in the body, especially in regard to disease prevention. Many of the food sources that contain phytochemicals discussed in the following sections are excellent choices to include in a sports nutrition plan for athletes. Although research has focused on health and disease prevention and not on sport performance, athletes can also reap the benefits of good health by consuming a phytochemical-rich diet. **Table 6.3** provides a summary of a variety of phytochemicals and examples of good food sources of these phytochemicals.

TABLE 6.3 Phytochemicals in Foods

Phytochemical	Food Source
Allium compounds	Garlic, onion
Anthocyanins	Blue and purple fruits, such as blueberries, grapes, cherries, raspberries
Carotenoids	Yellow, red, and pink fruits and vegetables; dark green leafy vegetables
Catechins	Green tea
Flavonoids	Most fruits and vegetables
Indoles, isothiocynates	Broccoli, cabbage, cauliflower, radish
Isoflavones	Soy foods
Lignans	Flax seeds, soybeans
Lycopene	Tomato products, watermelon, other pink fruits
Phenolic acids	Berries, grapes, nuts, whole grains

What are phenolic compounds?

The phenolic compounds are a large and varied group of phytochemicals that are found in many different foods. The majority of the research on phenols is related to their positive influence on heart disease prevention. The phenols are a broad category of antioxidant compounds that work to prevent the oxidation of LDL cholesterol. Common phenolic compounds that have been researched fairly extensively include flavonoids and phenolic acids.

Flavonoids became known to the public when research was published reporting that individuals who drink wine may have a decreased risk for heart disease. The flavonoids in wine and grapes started a revolution and much debate about the benefits of wine consumption in combating heart disease. The first link between wine intake and cardiovascular disease became apparent when a French research group[48] found a strong negative correlation between wine intake and death from ischemic heart disease in both men and women from 18 countries.[45] The French have a relatively high consumption of dietary fat and saturated fat, yet a relatively low rate of cardiovascular disease. The increased wine consumption in France may help protect against heart disease, and thus the "French paradox" was born. Some of the reduction in cardiovascular disease may be from the alcohol's ability to increase HDL cholesterol; however, the nonalcohol components of wine, the flavonoids, hold promise as well.

Grape seeds and skins are considered good sources of polyphenolic tannins that provide the astringent taste to wine.[49] The phenolic compounds catechin and anthocyanin are also abundant in grapes.[50] Red wine contains more flavonoids than white wine because the grape skins are incorporated into the fermentation process. The skins and sometimes seeds are used in wine making and in grape juices, making these products high in these phytochemicals. New evidence suggests that nonalcoholic wine and commercial grape juice can provide similar amounts of flavonoids and antioxidant capacity as red wine.[51,52] Because alcohol consumption is generally not recommended as part of an athlete's diet, sparkling grape juice can provide a healthy nonalcoholic alternative.

Teas contain both flavonols and polyphenols, most significantly catechins.[53] Green and black teas both contain these phytochemicals; however, green tea has been found to be more concentrated in polyphenols. This might be related to how the different teas are prepared for consumption. Green tea leaves are steamed and dried, which prevents oxidation of the polyphenols, primarily catechins. Black tea leaves are fermented, which reduces the amount of catechin in black tea compared to green tea.[54] Regardless of the type of tea, the primary antioxidant properties may act in cancer prevention[55,56] and cardiovascular disease protection.[57] Consuming several cups of green or black tea daily will help athletes reap the potential disease prevention benefits of this beverage. The teas can be found in decaffeinated varieties, containing the same beneficial ingredients. The decaffeinated versions are recommended to athletes to help them avoid excessive intake of caffeine.

What are organosulfides?

A growing amount of evidence from epidemiological studies has provided consensus that diets rich in fruits and vegetables are associated with lower risks of developing certain cancers. Several excellent reviews have been published to support this association.[43,44,58] The more difficult determination is what specifically in fruits and vegetables is the protectant. Many of the nutrients, fibers, and non-nutrient compounds in fruits and vegetables may play singular or additive roles in cancer risk reduction. The phyto-

chemicals found in the cruciferous (sometimes called brassica) vegetables and allyl compounds in garlic and onions may play a singular or additive protective role. The cruciferous vegetables contain a variety of organosulfide compounds, including glucosinolates, indoles, and isothiocyanates, and have long been touted for their anticancer properties.[59] Vegetables including broccoli, brussels sprouts, cabbage, rutabaga, and cauliflower are part of the organosulfide group of phytochemicals. Talalay and Fahey[60] present an excellent review of the role of glucosinolate and isothiocyanate phytochemicals found in cruciferous vegetables in cancer prevention. They cite more than 10 studies and report that "these findings provide additional support for the pivotal role of the glucosinolates and isothiocyanates derived from crucifers in chemoprotection against cancer" (p. 3029S).

Garlic and onions, along with leeks, chives, and shallots, contain allyl compounds that provide flavor and odor to foods. The allyl compounds in garlic have been researched for many possible health benefits, including reducing blood cholesterol levels and cancer risk, and for their antihypertensive potential. A review of more than 20 epidemiological studies suggests that allium vegetables, including onions, may confer a protective effect against cancers of the gastrointestinal tract.[44]

Athletes should include cruciferous vegetables, garlic, onions, and other pungent vegetables in their daily diet to gain the potential health benefits. However, consumption of these vegetables can produce intestinal gas and bloating that may be uncomfortable when training or competing in sport events. Therefore, athletes should avoid high-gas-producing vegetables within several hours before training. Consumption of these vegetables after workouts or competitions is the best practice to avoid uncomfortable gas production while reaping the health benefits.

What is lycopene?

Lycopene is one of the most well studied of the carotenoids and is more widely recognized by the public. Advertisements for vitamin and mineral supplements that "contain lycopene" abound. Lycopene is now added to many vitamin supplements marketed for men because of the strong correlation between lycopene intake and prostate health. Lycopene is the most abundant carotenoid in the prostate.[61] In the now classic prospective cohort study of lycopene's effect on the prostate, Giovannucci et al.[62] found that men who consumed at least 10 or more servings of tomato products per week had less than one-half the risk of developing advanced prostate cancer. The proposed mechanism for the reduced cancer risk is the antioxidant property of lycopene.

Tomatoes and tomato products such as ketchup, tomato pastes and sauces, canned tomatoes, and tomato-based products such as enchilada sauce, pizza sauce, picante sauce, and salsa are good sources of lycopene. Fresh tomatoes appear to have less bioavailable lycopene than processed tomatoes because cooking releases the lycopene stored in the cell walls of fresh tomatoes. Absorption of lycopene is greater with the simultaneous intake of fat. For example, a tomato-based pizza sauce on a pizza with cheese or an oil and vinegar dressing mixed with canned tomatoes for a salad will enhance the absorption of lycopene.

Future research may find that lycopene is beneficial in a variety of ways for active individuals. A small study of 20 individuals found that lycopene supplementation of 30 milligrams per day provided some protection against exercise-induced asthma.[63] Some research, primarily in animal studies, suggests that the antioxidant properties of lycopene may reduce oxidative stress.[64] Research on the effect of lycopene supplementation for providing protection from ultraviolet sunlight has shown some promise,[65,66] which could be significant for athletes who train and compete outdoors. However, many of these studies contained small sample groups, combined other antioxidant supplements with lycopene, and were conducted primarily in animals and not humans. Further research in larger human clinical trials, isolating lycopene, is needed before any definitive answers about lycopene's effects in these areas can be drawn.

gaining the performance edge

Phytochemicals are plant-based compounds that appear to have potent antioxidant and anticancer effects. Although DRIs have not been established for these substances, athletes can still reap the potential benefits by consuming a variety of fruits, vegetables, and other plant-based foods each day.

How can athletes increase phytochemical consumption through whole foods?

Increasing phytochemical intake means focusing on a plant-based diet. This does not mean that meat needs to be eliminated; it simply means more effort should be spent on trying to incorporate a wide range of fruits, vegetables, and whole grains into the daily diet (see **Training Tables 6.4 through 6.6**). There is still a lot to learn about the actual amount of certain phytochemicals in plants, how they react in the body, a recommended dietary intake, and their effect on athletic performance. Research on the specific phytochemicals is relatively new, and there are many more different types of phytochemicals than there are vitamins. Establishing DRIs for the various phytochemicals is currently an ongoing process that will take years to decipher; however, that does not diminish the importance of including these essential compounds in an athlete's daily diet.

Training Table 6.4: Sunshine Broccoli Salad

1 large broccoli head, cut into bite-sized pieces
1/4 cup purple onion, chopped
1/4 cup sunflower seeds
1/4 cup orange juice
8 oz plain or vanilla low-fat yogurt
1/4–1/2 cup raisins

Blend the yogurt and orange juice and set aside. Wash and prepare the broccoli and onion. Mix vegetables and sunflower seeds together in a large bowl. Pour orange juice and yogurt mixture over vegetables and seeds and mix thoroughly. Let salad sit in refrigerator for 2 to 4 hours before serving, if possible, to blend the flavors. Garnish with or mix in raisins.

Phytochemicals present: Organosulfides, polyphenols

Serving size: 1 1/4 cups (Recipe makes four servings)

Calories: 166 kcals

Protein: 6 grams

Carbohydrate: 27 grams

Fat: 5 grams

Training Table 6.5: Salmon Pepper Salad

2 fresh salmon fillets
1 red bell pepper
2 cups spinach leaves, washed
1 mango or papaya, sliced
2 tbsp fresh lime juice
1 tbsp olive oil
1 clove garlic, crushed
1 tsp dried thyme

Mix lime juice, olive oil, garlic, and thyme together in a small bowl. Rinse and pat dry the salmon fillets. Place fillets in a shallow dish. Pour the lime juice marinade mixture over the salmon; turn to coat. Cover the dish, place it in the refrigerator, and let marinate for at least 10 minutes.

Wash the spinach and spin or pat dry; tear into bite-sized pieces. Wash and core the red pepper; slice into thin strips. Peel the mango or papaya; slice into thin strips or small pieces.

Grill the salmon on an indoor or outdoor grill until fish flakes (approximately 4 to 6 minutes per side). Arrange salmon on bed of spinach and red pepper. Garnish with mango on top and around the fish. Serve with balsamic vinaigrette salad dressing, if desired.

Phytochemicals present: Lutein, zeaxanthin, and organosulfides; also high in vitamins C and E, and beta-carotene

Serving size: 3 oz salmon, 2 cups vegetables (Recipe makes two servings)
Calories: 286 kcals
Protein: 19 grams
Carbohydrate: 25 grams
Fat: 13 grams

Training Table 6.6: Berry Soy Smoothie

1 cup frozen blueberries, strawberries, or other berries
1 cup soy milk
$\frac{1}{2}$ cup orange juice
4 oz silken tofu

Let berries thaw slightly. Blend all ingredients in blender until smooth. Add enough orange juice and tofu to obtain the desired texture.

Phytochemicals present: Isoflavones, carotenoids, and flavonoids

Serving size: 3 cups (Recipe makes one serving)
Calories: 295 kcals
Protein: 14 grams
Carbohydrate: 42 grams
Fat: 9 grams

The following tips will help athletes consume more plant-based foods, thus increasing phytochemical intake:

- Serve hot or cold green tea with meals.
- Keep red or green grapes washed and ready in the refrigerator for snacks.
- Use tomato sauces and pastes and spaghetti sauce as a basis for meals.
- Sprinkle nuts and seeds on salads.
- Use garlic in cooking, dressings, marinades, and sauces.
- Prepare side dishes with green leafy vegetables such as kale, spinach, and collards.
- Use soy milk instead of dairy milk on cereal or as a beverage.
- Complement all meals with one or two fruits or vegetables.
- Use whole grain foods more often than processed grains.
- Try a new grain recipe that uses bulgur, barley, or oats.
- Eat fruit for dessert such as a baked apple, chopped melon, or chilled berries.

Athletes should be encouraged to eat a wide variety of foods, including many plant-based items, to assist them in obtaining the energy they need while also consuming valuable nutrient and nonnutrient components in their diet. As research evolves, recommendations similar to the DRIs may be on the horizon for some phytochemicals.

Food for Thought 6.3

You Are the Nutrition Coach

Apply the concepts from this chapter to several case studies.

The Box Score

Key Points of Chapter

- Contrary to the body's requirements for carbohydrates, proteins, and fats, the daily dietary requirements for vitamins are very small. However, these micronutrients serve vital functions in the body and thus are essential for survival.
- Vitamins are organic compounds that are essential to at least one vital chemical reaction or process in the human body. In addition, to be considered a vitamin the compound cannot be made by the body itself or be made in sufficient quantities to meet the body's needs. In addition, vitamins contain no calories and are found in very small amounts (i.e., micrograms or milligrams) in the body.
- Vitamin requirements are presented as a collection of dietary values termed the Dietary Reference Intakes (DRIs). The DRI expands on the previously established RDA and takes into consideration other dietary quantities such as EAR, AI, and UL. DRIs are continually being reviewed and updated as scientific data become available.
- Vitamins are categorized into two main groups: water soluble and fat soluble. The water-soluble vitamins include the B-complex vitamins, vitamin C, and choline. The fat-soluble vitamins include vitamins A, D, E, and K.
- The B-complex vitamins are actually a group of eight different vitamins. In general, the B vitamins serve as coenzymes in the metabolic pathways that break down carbohydrates, fats, and proteins for energy. Because they are water soluble, they are not stored in any appreciable amounts and thus present a low risk for toxicity to the body.
- Choline is a vitamin-like compound, but is not considered a B vitamin. Choline is involved in the formation of the neurotransmitter acetylcholine, which is needed for muscle activation. Choline has also been shown to help maintain the structural integrity of cell membranes. The risk for choline deficiency is low; however, toxicity can occur, presenting signs and symptoms of low blood pressure, diarrhea, and a fishy body odor.
- Vitamin C is one of the most recognized vitamins because of its supposed role in enhancing the immune system. It is a strong antioxidant, is critical for the formation of collagen, enhances iron absorption, and aids in the formation of various hormones and neurotransmitters.
- The fat-soluble vitamins are dependent on the presence of dietary fat for intestinal absorption and transport throughout the body. Fat-soluble vitamins can be more toxic to the body than water-soluble vitamins because they are stored in the liver and adipose tissues and can accumulate over time. Caution should be exercised when using supplements containing high doses of these vitamins.
- Vitamin A is associated with the retinoid and carotenoid families of compounds and is important for vision, healthy skin, and cell differentiation. A vitamin A deficiency can result in blindness and hyperkeratosis. Toxicity is rare when the dietary focus is placed on whole foods; however, intake from supplements can quickly reach toxic levels.
- Vitamin D is not only crucial for bone health but is also important for immune function, control of inflammation, and even muscle function. In fact, vitamin D deficiency has been associated with increased risk for several chronic and autoimmune diseases, such as hypertension, cardiovascular disease, rheumatoid arthritis, depression, and certain cancers. The growing evidence regarding the importance of vitamin D has caused some nutrition professionals to recommend serum vitamin D screening for athletes. Toxicity can result in hypercalcemia and subsequent calcification of various soft tissues throughout the body.
- Vitamin E belongs to the tocopherol and tocotrienol family of compounds and is most recognized for its antioxidant properties. Deficiencies are rare and so is toxicity. However, high levels of vitamin E can have a blood-thinning effect, thereby decreasing blood clotting, which can lead to bruising and other more serious complications.
- Vitamin K is probably the least recognized of the vitamins. The primary role of vitamin K is in blood clotting, but it also plays an important role in bone health. Deficiencies can result in substantial hemorrhaging. Toxicity from food sources is rare.
- Free radicals are highly reactive compounds that can damage cell membranes and other structures, including DNA. They tend to be compounds containing oxygen and can be formed during normal aerobic metabolism. Free radicals can also be introduced into the body from exogenous sources (e.g., pollutants in the air).
- Antioxidants are the body's primary defense against free radicals. They exist in enzymatic and nonenzymatic forms. Vitamins A, C, and E along with other compounds known as phytochemicals serve as the body's nonenzymatic antioxidants. The effectiveness of supplementing the diet with

nonenzymatic forms of antioxidants is presently unclear.

- Exercise, particularly aerobic exercise, has been shown to increase free radical production. Although the reasons underlying the free radical increase are not clear, the body's enzymatic antioxidant defense system may up-regulate as an adaptive response to extended training, thus increasing its natural defenses against free radicals. The effect of taking supplements of vitamins A, C, and E and phytochemicals on free radical levels during exercise is presently unclear. For now, making recommendations regarding antioxidant supplementation is not necessary or advisable. The best nutritional advice is to incorporate more antioxidant-containing foods into the daily diet.
- Phytochemicals are biologically active plant chemicals that are not considered nutrients but play a vital role in health. Although there are many different phytochemicals, research has associated three classes as aiding human health: phenolic compounds, organosulfides, and carotenoids.
- Athletes should be encouraged to eat a wide variety of fruits and vegetables to help ensure adequate intake of phytochemicals. Because DRIs have not been established for phytochemicals, the need for supplementation by athletes is currently unknown.

Study Questions

1. What are vitamins and how are they classified? List the specific vitamins that fall under each classification. Which classification of vitamins is potentially more toxic to the body? Explain why.
2. Taken as a group, what major role do the B vitamins play in the body? What implications does this have in regard to athletes and sport performance?
3. List two of the four fat-soluble vitamins and their respective roles/functions for overall health and athletic performance.
4. Should dietary substances that block absorption of fat by the digestive system be used? Defend your answer.
5. What are free radicals? Where do they come from, and what effect do they have on the body?
6. What are antioxidants? Which vitamins and related compounds serve as antioxidants in the body? Briefly describe how they work in the body.
7. Should athletes take supplements that boost the body's level of antioxidants? Defend your answer with what is currently known about these substances.
8. What are phytochemicals, and where do they come from?
9. What are some of the commonly identified classes of phytochemicals? What roles do they play in the body?
10. What are the current recommendations for the intake of phytochemicals? Should athletes take phytochemical supplements? Defend your answer.

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